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Pricing irrigation water according to the Water Framework Directive under Climate Change: impacts in a Mediterranean agricultural area.

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ABSTRACT

A key guideline of the European Water Framework Directive (WFD, 2000/60/EC) asks to cover water costs in a way to encourage the efficient use of the resource, and therefore its protection. Specifically, it requires to adopt effective pricing instruments that establish a direct linkage between water use and payments, in order to charge the full cost for water services (FCR) to end-users (also agricultural). However, it recommends to do this while minimizing possible adverse environmental, social and economic impacts. Currently, this is a challenging goal that arises perplexities, or even warnings, among policy-makers, local administrators, researchers and, not last, farmers. Climate Change (CC) exacerbates these concerns, as it is projected to exert growing pressures on water resources in the Mediterranean area, due to the increase of crop irrigation needs, and to the parallel decrease of water availability, both going subject to higher inter-annual variability. In particular, the negative impacts of CC could strengthen those expected from the implementation of the WFD on economics and employment in the territories involved, hampering anyway the achievement of its environmental objectives. This analysis estimates how alternative pricing systems and increasing levels of cost recovery for water supply, up to FCR, could affect the agricultural use of water and of other resources, as well as farm incomes, comparatively in the current (2000-2010) and in a near future (2020-2030) climate scenario. In this way the impacts of CC and of the implementation of the WFD are jointly assessed. The simulations are based on a territorial economic model of Discrete Stochastic Programming that represents the use of irrigation water in an Italian Mediterranean area, where a Reclamation and Irrigation Board (RIB) supplies irrigation water to associated farms and applies an area-based pricing system. As in the case of many Italian RIBs, current tariffs cover only a part of the total water cost, while the remainder is supplemented by regional authorities as a form of compensation for local and climatic disadvantages. The results should provide to stakeholders and policy makers a useful guidance for implementing WFD in a context in which the CC may severely alter the conditions for using water resources, and there may be some adaptation issues relevant to such changes.

KEYWORDS

Water Framework Directive, pricing irrigation water, water distribution cost function, climate change, mathematical programming.

SOMMARIO

1. INTRODUCTION

Climate Change (CC) is prospected to exert growing pressures on water resources in the Mediterranean area, due to the increase of water requirements, and to the parallel decrease of water availability, both going subject to higher inter-annual variability. In their study about the impact of CC in the Mediterranean region, Giorgi and Lionello (2008) predict a pronounced decrease in precipitation, especially in the warm seasons, along with a temperature increase, particularly in the summer. In this season, moreover, inter-annual variability is projected to dramatically increase, what could add to the described trend for temperatures and precipitations, leading to a greater occurrence of extreme weather events. Demand of water for crop irrigation could significantly increase, along with competition for water and water stress, as reported by Faloon and Betts (2010). This is confirmed, among the others, by the more recent findings of García-Garizábal et al. (2014) in their study about the historical dynamics and future projections of climate in the Middle Ebro Valley (Spain) Irrigation District: the Authors state that CC is affecting agriculture doubly, since evapotranspiration requirements increase at the same time that water resources decrease, and that these effects are felt especially in irrigated agriculture, since the growing cycles of the main crops coincide with the months most affected by CC.

Similar considerations have been made by Dono et al. (2016), analysing the impacts of CC on a farming district of Insular Italy (*Oristanese* area, Sardinia). These Authors consider that temperature and precipitation anomalies in the near future could show a high seasonal heterogeneity. Furthermore, minimum and maximum mean temperatures may increase in all seasons, with a stronger signal in the summer, while seasonal mean values of precipitation are expected to decrease, slightly in winter and strongly in spring (-33%). Given the potential for influencing water requirements and availability, ignoring climate variability and change in critical crop phases could nullify the Programmes of Measures

(POMs) over time, not meeting the environmental targets of the rural basins management (Wilby et al., 2006), as well as undermining the water management policies, with disproportionate costs for the resource users. In this regard, the impact of CC on the implementation of the European Water Framework Directive (WFD, 2000/60/EC) in the near future is particularly interesting. In fact, the European legislator asks Member States to implement water policies that aim to protect water resources from excessive exploitation and pollution, and to do this by ensuring, also for irrigation water, the full recovery of the costs for water services through pricing systems that establish a direct link between water use and cost. In agriculture, the impacts of implementing the WFD are likely to overlap with those of CC, whose effects could hinder at some extent the full achievement of the objectives set by the Directive.

2. BACKGROUND

2.1. Effects of climate variability and change on agriculture and their assessment in the Mediterranean area

In analysing the meteorological conditions of a climatic zone on decennial time periods, it is always found in its sub-areas a significant inter-annual variability that also applies in periods when the climate is perceived as in a stable condition. This variability is generated by the combination of different mechanisms. High frequency mechanisms due to atmospheric dynamics dominate the local climate variability in each month and season. A smaller amount of variability is due to multi-annual and decadal low frequency mechanisms mainly driven by the ocean dynamics. Finally, there is a long term trend induced by global warming: in recent decades this has accelerated, acting both as incremental component, both by modifying the mechanisms of high and low frequency, and the variability that induce.

The inherent variability of the Mediterranean climate is mentioned and explained by many studies highlighting the determinants and expressions of climatic variables in the different sections of this region (Navarra and Tubiana, 2013). It was shown that the atmospheric circulation in the Atlantic Ocean determines the variability of rainfall in the autumn period (Delitala et al, 2000; Altava-Ortiz et al, 2011). Similarly, it was shown that heat waves are a frequent feature of the Mediterranean summer (Colacino and Conte, 1995; Matzarakis and Mayer, 1997; Gaetani et al, 2012), and several anomalous warm summers have occurred in the Mediterranean and in southern Europe over the last 60 years, with hot events of different intensities and lengths (Baldi et al., 2006; Segnalini et al., 2011).

The influence of climate variability on crop production and livestock is also extensively treated in the scientific literature. Many researches made use of specific mathematical and statistical models to investigate the relationships between variability in the climatic conditions and livestock production (Johnson, 1987; Nienaber et al, 1999; Vitali et al, 2009; Bertocchi et al, 2014; Bernabucci et al, 2014). Other analyses relied on models providing a rich characterization of optimal growth and represent the response of crops production under different climatic conditions (Brown et al, 2000; Liu and Tao, 2013). In various studies these models are used to assess the impact of CC by comparing crop yield or the requirement of inputs under conditions of current and future climate (Eckertsen et al., 2001; Semenov and Shewry, 2011; Rötter et al., 2012; Olesen et al., 2011; Palosuo et al., 2011; Reidsma et al., 2010). There is also growing recognition of the importance of assessing the effects of CC, and possible adaptation strategies at the agricultural system or farm household level (Claessens et al., 2012), rather than focusing on aggregated results that can conceal large amount of variability.

Farm and regional scales are also suitable to the economic modelling that analyses the impact of CC on agricultural decision-making processes. The estimated relationship between climate variability and agricultural activity can, in fact, be included in

Mathematical Programming Models (MPMs) simulating economic choices of farms in the context of production risks (Matthews et al., 2013). One of those models, Discrete Stochastic Programming (DSP) (Hardaker et al., 2004), was used to represent the economic impact of many agricultural uncertainties: availability of irrigation water (Calatrava and Garrido, 2005a, 2005b), weather risks (Mosnier et al., 2009), change in climate variability (Dono and Mazzapicchio, 2010, Dono et al., 2013b).

2.2. The Water Framework Directive

The WFD was adopted with the general purpose of establishing a normative framework for the protection of waters from excessive exploitation and pollution and the enhancement of the status of aquatic ecosystems, as well as of those ecosystems (i.e. terrestrial and wetlands) that directly depend on them. To this end, aims at promoting sustainable water use based on long-term protection of available water resources. With reference to surface waters, Member States are asked to implement the necessary measures not only to prevent further deterioration, but also to protect, enhance and restore the status of water bodies, according to the principle of Community action known as "polluter pays" (OJEC, 2000).

For achieving these objectives, a priority was given to the economic principle of the Full Cost Recovery (FCR) for water services (including financial, environmental and resource costs), through the implementation of water policies providing adequate incentives for users (agriculture, industry and households) to use water resources more efficiently (WATECO, 2003). These incentives are thought to be given through the adoption of effective economic instruments of pricing, warmly recommended. As evidenced by Gallego-Ayala et al. (2011), volumetric pricing has primarily been seen as the most suitable tool, because accurate water-metering is often considered a pre-condition for making water-users face appropriate costs for water usage.

According to the Italian Institute of Statistics (ISTAT, 2014), Italy is among the countries that make more extensive use of irrigation in Europe, with 11.1 billion cubic meters withdrawn in 2010, to irrigate about 2.5 million hectares. Irrigation water is mainly supplied by Reclamation and Irrigation Boards (RIBs), that in 2010 covered about 91% of irrigated surfaces (INEA, 2011), so RIBs are the main recipients of the WFD principles. Water pricing policies, to be implemented by River Basin Authorities in River Basins Management Plans, should embody the latter and aim at addressing a number of different focus issues at the same time, namely efficiency in water allocation, revenue adequacy, administrative simplicity, transparency, flexibility and equity (Cooper et al., 2014). However, these Authors note that some of these objectives might be in conflict with each other (e.g., reaching economic efficiency could contrast with ensuring revenue adequacy, and both could be with addressing equity), so that it is likely to be quite hard to reconcile all in a single policy. This is why Berbel et al. (2011) suggest to adopt a combination of technical and economic measures, rather than simple economic instruments, in full agreement with other empirical findings (Liao et al., 2007; Gòmez-Limòn and Riesgo, 2004; Bazzani et al., 2005; Dono and Giraldo, 2012). These evidences are warning about possible negative impacts on farm incomes and redistributive effects among farm typologies, but also the likely adverse impacts on labour employment in the agricultural sector should not be neglected (Berbel and Gomez-Limon, 2000; Aidam, 2015). Remarkable divergences aroused among European agricultural economists on the opportunity of fully implementing WFD, as well as on the modalities in which this should be done, thus recognizing opportunities and threats. Focusing on Italy, there is no doubt that the pricing systems adopted by Italian RIBs make users pay for irrigation water on average less than other European users (Berbel et al., 2007). In fact, commonly adopted pricing systems are in large part area-based, and usually cover the only operative component of water cost (Chohin et al., 2003; Dono et al., 2010). Moreover, part of the latter is frequently subsidized by Regional Authorities, due to local geographical handicaps. This fact is, according to Molle and Berkoff (2007), the main responsible for the current trend of excessive and unsustainable use of water resources. However, they also state that, when applied, FCR reveals successful in reaching its primary goal, but elusive in determining concrete increases in efficiency. This happens because water demand curve reveals inelastic at low water prices ranges (De Fraiture and Perry, 2007), so concrete increases in efficiency are achievable only through dramatic increases of tariffs, going far beyond FCR. Nevertheless it was argued that achieving greater economic efficiency might be not necessarily optimal if environmental and social aspects related to water use are taken into account, as required by the same WFD (Llop and Ponce-Alifonso, 2016). Furthermore, in the context of most Italian RIBs, where water consumption at farm level is unmetered, gains in economic efficiency gettable through FCR would be curtailed by the transaction costs that would be inevitably involved if this is achieved by the volumetric pricing (Giraldo et al., 2014; Galioto et al., 2013).

Article 9 of the WFD explicitly recognizes that modifying the currently adopted pricing systems and pursuing FCR could raise social and redistributive concerns, and establishes that Member States may consider social, environmental and economic impacts in planning the mode and level of cost recovery. This aspect is important. On it, Reynaud (2016) shows that increasing water payments for domestic use could mainly affect the most vulnerable social groups. From the agricultural perspective, Venot (2008) stresses that raising taxes on the water taken from farms wells does not involve significant savings of that resource, and can further reduce the profitability of extensive crops or low income. In the case of irrigation water supplied by collective facilities, Dono et al. (2010) stress that if the latter are underused, FCR rates could be based on average costs that are much higher than the marginal costs: uncontrolled extractions of groundwater may result where this resource is available, or negative impacts on incomes where not. Definitely, pursuing FCR by increasing water payments might generate a vicious circle favouring the use of sources difficult to protect, appreciably affecting low income users and reducing the use of collective services (Azevedo and Baltar, 2005; Reynaud, 2016).

Anyway, according to a recent report, the European Commission stresses that not all Member States apply transparent water pricing, and Greece and Italy are particularly lagging behind in adapting (European Commission, 2015): a solicitation arises for many national and local water authorities, to recover the delay.

2.2.1. Aspects of scientific debate on WFD relevant for the analysis

Several aspects of the scientific debate on WFD are relevant to this study. A first issue is identification of the costs to be recovered in agriculture: Garrido and Calatrava (2010) classify monetary costs in three categories. The irrigator pays private costs as any other farming cost, such as energy, maintenance and labour. The pricing and water allocation policies can have major impacts on them, leading to change the source of supply, for example encouraging use of groundwater, or the adopted irrigation technologies. Another category is represented by the costs of the irrigation district, or scheme, for the management and maintenance of water distribution systems to individual farms, pertaining to the RIBs. Finally, the Water Authority costs pertain to governmental agencies that manage large dams and infrastructures, debiting related costs to end-users and taxpayers: and it is interesting to examine the distribution between the two groups (Garrido and Calatrava, 2010). Complex and site-specific analyses are required to estimate and include in water costs the environmental and resource components. The former consist of non-use values associated with obtaining a healthy functioning of aquatic ecosystems, and use values of water environment (DG ECO 2, 2004). The latter arise when alternative uses of the water generate higher economic value than present use or foreseen future, because of an inefficient water allocation or pollution, over time and across users (EEA, 2013).

Several Authors agree that applying FCR would increase the water users payments, mainly to agriculture that currently pays part of the financial costs (Berbel and Gomez-Limon, 2000; Massarutto, 2007; Berbel et al, 2011; Giannakis, 2016). According to EEA (2013) volumetric water tariffs of Italian agriculture are in the range of 0.04–0.25 €/m3, over 0.002-0.70 €/m3 in a selected group of European countries; flat rates are in the range of 30–150 €/ha, over 30-210 €/ha for those same countries. Arcadis (2012) estimate that those charges generate a 50% financial cost recovery rate, as average of 50-80% in the North, and 20-30% in Southern Italy. Massarutto (2003) mentions analogous levels of partial recovery of the total cost. He also highlights the complexity of this computation, warning that in many facilities the final cost value depends on the joint use in multiple uses, as the hydropower generation in Northern Italy, and public water supply companies in South. The Author also reports that operative costs are recovered at 70-100% in Northern Italy, and 20-100% in the South.

Related to FCR, another relevant issue concerns the pricing system that can encourage efficient use of water. Volumetric is considered as the most suitable pricing for achieving the WFD objectives (Gómez Limón and Riesgo, 2004; Bartolini et al., 2007; Gallego-Ayala, 2012). Yet, many constraints are found to possibly hinder the reaching of efficiency in irrigation water (Johannson et al, 2002). Massarutto (2007) stresses that recovery should only consider costs incurred by an efficient service supplier that pays all inputs at their marginal cost (MC). Furthermore, Dono et al (2013a) highlight that MC pricing may not allow FCR when average costs (AC) are decreasing, as in large canal schemes, being MC lower than AC. Other factors, such as scarcity due to CC, may reduce the use of water at levels where MC of running collective facilities is below AC. In conditions of structurally decreasing irrigation AC, or under-utilized irrigation schemes, FCR pricing would charge farmers for inefficient levels of use that do not depend on their choices.

Furthermore, Dono et al (2010) stress that FCR of water services achieved by increasing payments could hinder water protection, encouraging farmers to use alternative sources as groundwater or rivers. According to Reynaud (2016) the implementation of FCR would result in major changes in water use of households (in Italy among other countries), as well as in accessibility issues, since (not Italian) families in the lowest income decile will have to devote major shares of their income to pay the new water bills and wastewater. Moreover, inconsistency aspects are present: Garrido and Llamas (2009) point out that specifying the resource cost would require functioning water markets; yet, if this trade becomes a usual practice, there will be no need to integrate the resource element in the water costs. In any case, according to Howarth (2009) a critical aspect is that WFD, and the documents on its application, are vague in defining the criteria to assess these issues. Gómez-Limón and Martin-Ortega (2013) stress that the vagueness of Article 9, can also lead to conclude that it is not required to apply increases in water tariffs. Also because of this vagueness, many river basin plans are mainly descriptive and devoid of prospective analysis. Hence, it would be useful strengthening their economic section to avoid that their choices appear arbitrary in tempering the social impact of FCR, and in protecting environmental quality.

2.3. Water Framework Directive, Climate Change and Mathematical Programming Models

Several studies so far have focused on the analysis of the economic impacts expected from the application of the WFD to local and regional contexts. Bazzani et al (2005) use a multi-criteria MPM to conclude that WFD would reduce only slightly agricultural water use, and would mainly reduce farm income and labour employment, even if differently among farm types. Mejias et al (2004) use a stochastic MPM to show that pricing would be even less effective in reducing farming use in the years of increased water scarcity. Instead, integrating objectives of WDF and CAP would increase the efficiency of water allocation.

Riesgo and Gomez-limon (2006), and Bartolini et al (2007) use a MPM, respectively, with linear and multi-attribute utility, to conclude that agricultural policies are pre-eminent on the recovery, partial and complete, of the irrigation water costs. They also conclude that it is useful even to maintain low water prices to achieve the environmental objectives of WFD. Finally, looking more specifically at the environmental aspects, Semaan et al (2007) integrate the results of the EPIC crop model in a MPM, to conclude that water pricing is ineffective in reducing nitrate leaching; it is also socially resisted because, as the taxes on nitrogen fertilizer, charges farmers the cost of nitrate leaching reduction.

This study proposes a MPM of a Mediterranean irrigated area that allows a significant step forward respect to previous studies focused on Italy. First of all, extending the temporal horizon of the analysis to consider also the impact of the application of the WFD in a near future scenario of CC.. Then, comparing the impacts expected applying various alternative pricing systems, in addition to the volumetric, at increasing levels of cost recovery for water services, which are intermediate between the current and FCR. The model is based on DSP, that represents a particularly suitable tool to deal with climate-generated uncertainty. The latter is exacerbated by CC and affects decisional processes for the allocation of resources, in particular water. Calibration is made using Positive Mathematical Programming (PMP), which is also appropriate to assist the implementation of WFD pricing and cost recovery scenarios.

2.3.1. Discrete Stochastic Programming Models

The effects of climate variability on farmers' choices can be represented by a DSP model of supply (Cocks, 1968; Rae, 1971; Mccarl and Spreen, 1997; Hardaker et al., 2004; Connor et al., 2009). DSP allows to treat many agricultural choices that are subject to uncertainty, as they depend on variables whose exact values are not known at the time of the decision and will only occur later in the production process. The farmer can only formulate a hypothesis about the Probability Distribution Functions (PDFs) of these variables, and DSP assumes that farmer discretizes the PDF in main states of the nature, with their representative values and probabilities. DSP also assumes that, once the uncertain variable is achieved, i.e., one of its states occurs, farmer may take corrective actions if the outcome is different from the expected: this generates a cost that reduces the income level that can be potentially achieved. This cost of uncertainty may increase if the CC modifies the climate variability, which changes probability and representative values of the various states, or the ability to correct the effects of unfavourable conditions.

In the light of these characteristics, DSP has been widely employed to model the allocation of agricultural resources, particularly water, in conditions of uncertainty. Garrido and Calatrava (2010) stress that MPMs overvalue the economic impacts of pricing policies and undervalue water demand elasticity because of its short/medium-term perspective, besides neglecting the uncertainties involved in farming. Stochastic Programming models may help in representing the effect of various types of risk or uncertainty on the agricultural water demand (Hardaker et al, 2004; Garrido and Calatrava, 2010). Quiggin et al (2010) use DSP to evidence the long-run role of water reallocation in limiting the adverse impacts of CC, and claim for global adaptation policies and pledge of local governs in protecting the environmental flows. Dono et al (2013b) use a DSP model to investigate the concurrent impacts of CC on irrigation water availability and crop water needs, and stress the potential of EU Rural Development Policy in assisting RIBs to improve management and functionality of collective water infrastructure. Kahil et al (2015) use DSP to derive the ability of policy-assisted water markets in driving farmers' adaptation to CC.

2.3.2. Positive Mathematical Programming

Many of the above mentioned studies use the Positive Mathematical Programming (PMP) to perfectly calibrate the water allocation models. Iglesias and Blanco (2008) recommend

PMP to assist in implementing the WFD pricing and cost recovery, given its accuracy and replicability in diverse contexts. Cortignani and Severini (2009) extended the approach of Rohm and Dabbert (2003) to calibrate the PMP in order to simulate the application of new strategies and irrigation technologies. This enabled to overcome the dependence of the PMP from observed reality, which in other ways prevents to obtaining adaptive responses based on new activities. Dono and Giraldo (2012) show the potential of PMP to assist water policy analysis, highlighting that volumetric pricing of water from a dam could increase over-extraction of groundwater, and speed up the on-going salinization of aquifers. PMP allows to establish interactions amongst economic, hydrological and other biophysical sub-models in complex multi-module models, given the ease to apply in several contexts thanks to its self-calibrated approach (Howitt et al, 2012). Dagnino and Ward (2012) use PMP to assess the effects of an incentive-assisted policy that encourages farmers of a sub-basin in North America's Rio Grande to convert from surface to drip irrigation. They show that, in face of a consistent reduction of farm-level water usage, a relevant shortcoming is represented by the increase of water depletion at sub-basin level, because increased irrigation efficiency generates higher yields and higher ET, moreover without the possibility of restoring aquifers through percolation. Finally, Gohar and Cashman (2016) stress that, producing smooth changes, PMP adequately assesses CC impacts on water and food security, as well as many scenarios of adaptation and cost of water, in dynamic optimization frameworks.

3. OBJECTIVES OF THE ANALYSIS

The present study compares different pricing systems and levels of cost recovery for irrigation water, which are differently compliant with the provisions of the WFD. This is made using a DSP model of a Mediterranean agricultural area of west-central Sardinia (Italy), where a RIB operates and maintains the collective structures that distribute irrigation water to the associated farms. As will emerge from the results, achieving all the goals set by the Directive at the same time relying only on the recommended principles and instruments is fairly difficult. In this sense, it will clearly be highlighted that an ideal pricing system and level of cost reco recovery, allowing to achieve a more efficient water use while not involving negative economic, social and environmental impacts, do not exist for the considered study area. In the light of this, such possible impacts, economic and of resource use, are assessed. Furthermore, a comparison is made among those expected under the current climate and under a near future scenario of CC. The findings achieved may in first place concretely help policy-makers for defining, in concert with the RIB, a water policy that fits to the complexity of local agricultural systems, deemed representative of a large part of the Mediterranean ones. Secondly, they could be useful to farmers for understanding the mechanisms behind water costs formation, and for undertaking actions aimed to make a more efficient use of water resources.

The next section, Materials and Methods, first provides an overview of the modelling approach followed in the analysis, than passes on to describe the study area with particular reference to the RIB sub-zone, its irrigation districts and the farm typologies operating in it; analyses the sources of agricultural uncertainty related to climate, and mentions the climate, crop and livestock models employed to generate the input data for the economic model, as well as the procedures for their statistical elaboration. Finally, describes the structure of the economic model, the approach for assessing the different cost components of irrigation water, and the pricing systems and cost recovery scenarios. The Results section shows, for both climatic scenarios, the impacts of the simulations on area production activities, resources usage, and economic (global and redistributive) results. Then, provides an integrative focus on the impacts at the level of irrigation districts. The Discussions and Conclusions sections evaluate the impacts of the different pricing systems and levels of cost recovery, and discuss their effects in the future by comparing with their impact in the present.

4. MATERIALS AND METHODS

Simulating the economic impact of CC on a complex agricultural system necessarily requires to adopt a multidisciplinary approach, starting from the simulation of crucial agro-climatic variables under the single climate scenarios through climate models. These outputs are then used to feed crop and livestock models that simulate productive responses of local agriculture to climate. Finally, the latter are introduced in the economic model, which should more properly be defined bio-economic, as it in this way combines a biophysical and an economic component (Flichman, 2011). To properly account for the effects of climate variability and change, this study is based precisely on a modeling chain that integrates the outputs of climate, crop and livestock models into the area economic model, in a similar way to what proposed in Dono et al. (2016). Its construction starts from the employment of climate models to produce scenarios representative of the current and future climate, then uses these climate outcomes to feed crop and livestock models, which simulate the productive responses of the different activities performed, and finally integrates these result in the input matrices of the economic model, which suggests the optimal allocation of resources to maximize area gross margin in the face of climate uncertainty. Going beyond the modeling effort by Dono et al. (2016), the present study integrates in the economic model the simulations of alternative pricing systems and levels of cost recovery for RIB irrigation water, in order to evidence the impacts of the application of the WFD.

The following Figure 1 synthesizes the modelling chain lying at the base of this study, whose single components are described more in detail later in this section.

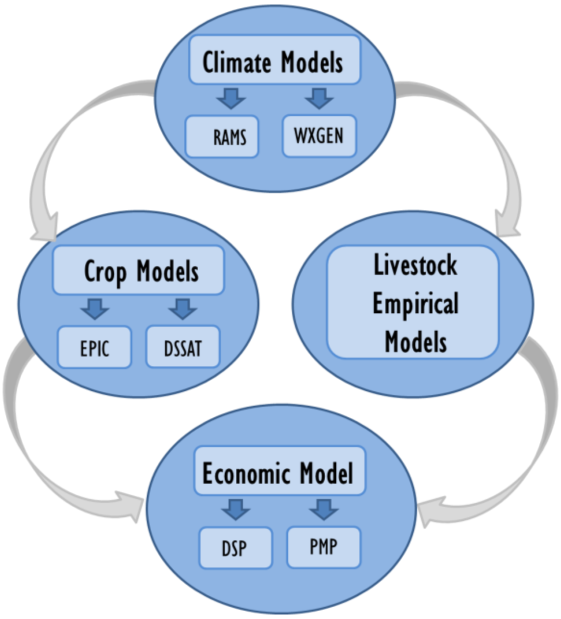

Figure 1. Description of the modelling approach followed in the analysis.

4.1. Study area and farm types

The *Oristanese* area is a 54,000 ha farming district located in the center-west of Sardinia (Italy). The agricultural system was reconstructed with reference to the situation of the year 2010, using the data of the Italian 6th General Agricultural Census, of the Farm Accountancy Data Network (FADN), and of the *Consorzio di Bonifica e Irrigazione dell'Oristanese* (hereinafter, *Oristanese* RIB), that supplies irrigation water to part of the area. The productive conditions of crops and livestock in this area were derived from interviews to farmers, agronomists, leaders of the Regional administration and of the local agricultural cooperatives. The requirements of labor, chemicals, and water were defined for the various stages of production of the crops, including yields. Similarly, the feed requirements of the various categories of livestock were specified, with the actual food rations and the products obtained. The prices of the production factors were also collected. The *Oristanese* agricultural district can be divided in two sub-zones depending on the presence of the RIB facilities.

In one sub-zone, that is the object of this study, the RIB supplies water from the *Eleonora d'Arborea* dam, with a reservoir of some 450 Mm^3, of which 120 Mm^3 are yearly made available to potentially irrigate 36,000 ha. The main irrigated cropping systems are based on cereals, mainly silage maize and rice, and other forage crops, mainly alfalfa and Italian ryegrass, but includes also horticultural crops such as artichokes, watermelon and tomatoes, citrus orchards, olive trees, vineyards, durum wheat and barley. The breeding of dairy cattle of Sardinia is largely concentrated in this RIB sub-zone (*Arborea* district), with a well-organized cooperative system for production, processing and marketing of cow milk.

Figure 2 contextualizes the study area and delimits the *Oristanese* RIB, as well as the administrative boundaries of the Municipalities that are served by its facilities. As evidenced, the RIB territory is formed by the merging of two pre-existent Boards, the *Campidano di Oristano* and the *Piana di Terralba e Arborea*, approximately separated by the Tirso river, whose water is stored in the *Eleonora d'Arborea* dam visible in the top-right of the first image. The territory of the *Oristanese* RIB is articulated into 26 independent irrigation districts. Based on their technological features, the latter can be grouped into three clusters. The first distributes water at high pressure ($HP > 2$ atm) with pipelines and pumping schemes. A similar network provides water at low-pressure ($LP > 1$ atm) in another group. Finally, a network of open channels conveys water by gravity (*GR*) in a third group. The unitary amount of the current acreage-crop fees is modulated depending on the benefit that farms gain from irrigation, as a function of the distribution technology and of the location. With regard to this latter aspect, the *HP* is further divided into a cluster for the districts of the Arborea municipality (HP_{Ar}), where higher fees are imposed, and in another *HP* cluster (HP_{Ot}) for the districts outside Arborea. Hence, four *macrodistricts* compose the RIB area: HP_{Ar}, HP_{Ot}, *LP* and *GR*, with a decreasing level of benefit.

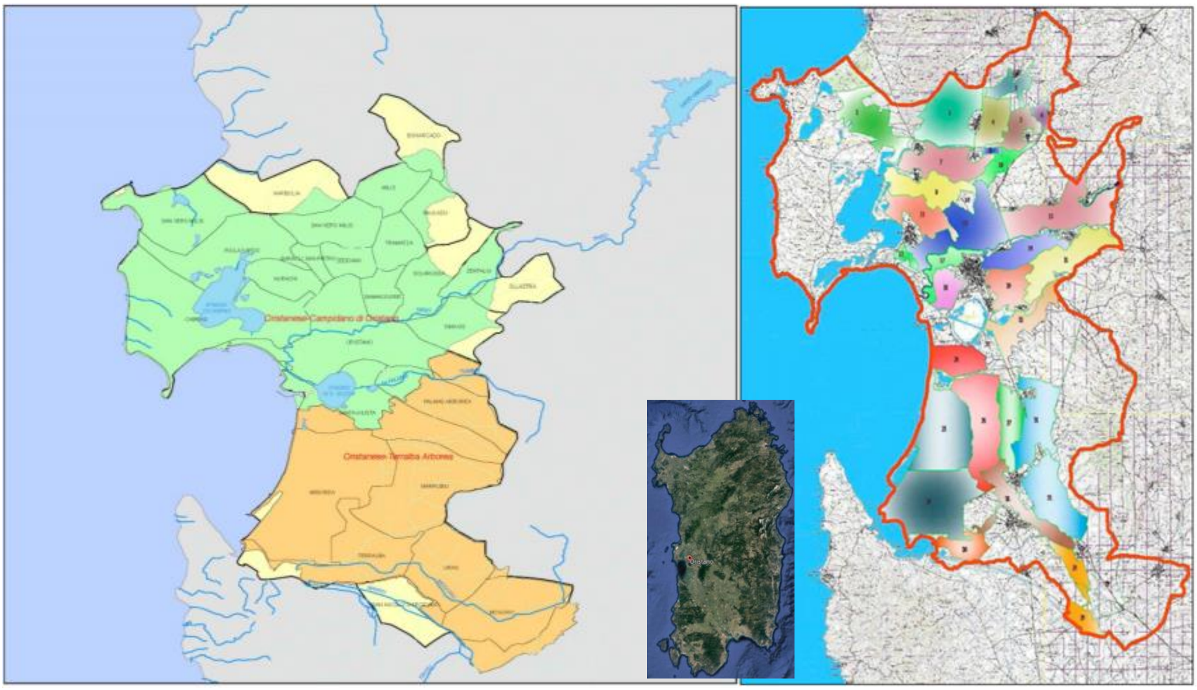

Figure 2. Territorial view highlighting the portion of the *Oristanese* Study Area in which the RIB facilities operate, with its articulation into irrigation districts. Source: SIGRIAN – INEA, modified

The rain-fed sub-zone, that does not represent the object of this study, covers some 18,000 ha, where occasionally a limited amount of water is available, taken from wells in some farms. The impossibility of making an extensive use of irrigation, given also the very low amount of rain per year in the area (about 620 mm on average in 2000-2010), determines a typically Mediterranean composition of agricultural landscape in this sub-zone: 55% of the agricultural land is made of pastures, tares, woods or set-aside fields; durum wheat and barley predominate on the rest of land. The dairy sheep industry is largely present in this sub-zone and involves some 372,000 sheep and a number of small sheep milk processing plants.

The structural and economic characteristics of this agricultural system have been represented in a regional economic model composed of blocks that identify the representative farm types of the area. The latter were obtained using data on FADN farms present in that geographic region: specialist rice (*RISP*), specialist citrus fruits (*CITR*), specialist dairy cattle (*CAT*), specialist vegetables grown under greenhouses (*GRH*), mixed cropping (MIX), and specialist sheep (*SH*). Additional analyses and elaboration were carried out to capture differences among farms of the same types. For the specialist dairy cattle, mixed cropping, and specialist sheep farm types, a cluster analysis was carried out to subdivide farms of these three types into more homogeneous groups considering some structural, economic and managerial aspects. Specifically, a hierarchical cluster analysis was first performed based on average linkage between groups, which involves the measurement of intervals with Euclidean squared distances for selected characteristics of the population. This resulted in a more preferable number of groups. The number of groups was calculated with a non-hierarchical clustering k-means method to aggregate the FADN farms by maximizing the internal similarity of the groups.

For the *CAT* farms, the total FADN sample was divided into two groups with a better-performing group (*CATA*), which has more economically efficient feeding and a shorter calving interval compared to the *CATB* group. Similarly, specialized FADN sheep farms were clustered into three groups (*SHA*, *SHB*, *SHC*), largely depending on the availability of irrigation to produce the forage. The *MIX* type farms were divided into five homogeneous groups that differed according to cropping patterns, structural characteristics, and location [in irrigated zone: Vegetables–Cereals (*MIX1*), Cereals–Forages (*MIX2*), Tree-arable crops (*MIX3*); in rain-fed zone: Vegetables–Fruit (*MIX4*), Cereals–Forages (*MIX5*)].

All thirteen farm types are representative of the average of the various characteristics within the FADN sample. Representativeness was ensured using the FADN database and other local sources to confirm accurate reflections of resource use and economic results in the study area. Each farm type was multiplied by the proportion of farms in the study area it was estimated to represent.

A synthetic description of the farm types and a measure of their territorial representativeness are provided in Table 1, where these are sorted in descending Net Income (NI) order. The table also reports useful information about the cropping mixes that are currently practiced, the subsequent irrigation water requirements (in terms of average watering intensity), and the incidence of water payments on NI. Looking at the latter indicator, immediately appears evident that the cost incurred by farms for irrigation is generally modest, and is not directly correlated with watering intensity. This is due to the fact that, as mentioned, the current pricing does not account exclusively for actual water use, but takes into consideration also the benefit gained from irrigation, as well as the cost that the RIB incurs to supply water to farms. Both these depend on the distribution technology (*HP*, *LP*, *GR*) adopted in the different *macrodistricts*. For instance, *RISP* farms present an incidence of water payments on NI that is only slightly higher than in other farm types, in face of a watering intensity that is three times higher. This is explained considering that for supplying water by gravity to these farms the RIB does not incur any energy cost, which in the other *macrodistricts* represents a preeminent component of total distribution cost, as directly related to water pressure.

Table 1. Description of the main farm types operating in the RIB area, as reconstructed from the Italian 6th General Agricultural Census and from the FADN database.

Farm type	N. of farms	Cropping activities	Livestock activities	Average acreage	Average NI	Average watering intensity	Incidence of water payments on NI
				Ha	,000 €	m3/Ha	%
CATA	130	**Silage Maize**, **Ryegrass**, Alfalfa, Other cereals, Clover	Dairy Cattle (108 lactating cows)	49	208.6	3,215	2.9
RISP	24	**Rice**, Other cereals, D. Wheat	-	129	181.0	11,981	5.3
CATB	40	**Silage Maize**, **Ryegrass**, Alfalfa	Dairy Cattle (110 lactating cows)	53	164.9	3,511	4.2
MIX2	55	**D. Wheat**, **Clover**, Silage maize, Ryegrass, Rice	-	139	86.8	1,096	3.8
SHA	45	**Clover**, **Pasture**, Alfalfa, Other cereals, D. Wheat	Sheep (88 lactating sheep)	89	50.9	502	1.6
CITR	68	**Citrus Fruits**, Artichoke	-	10	40.2	4,032	1.8
MIX1	562	**D. Wheat**, **Horticultural crops**, Hay crops, Silage Maize	-	18	34.1	3,571	3.4
GRH	46	**Horticultural crops**, Silage Maize, Ryegrass	-	14	26.2	3,458	4.1
MIX3	100	**D. Wheat**, **Tree crops**, Horticultural crops, Hay crops	-	5.0	10.7	2,660	1.6

Table 2 illustrates the distribution of the farm types across the four macrodistricts. As will be explained, this represents a key driver of the impacts occurring under the simulations of alternative pricing systems and levels of cost recovery. From one side, such impacts depend on the current level of cost recovery, that is greatly uneven among macrodistricts, and is differently modified under the various simulations. From the other, the distribution technologies adopted produce a different responsiveness of the distribution cost to variations in its determinants (i.e. the acreage of irrigated land and the average intensity of watering).

Table 2: Distribution of the farm types among the different macrodistricts

Farm types	HP_{Ar}		HP_{Ot}		*LP*		*GR*		*RIB*	
	N. of farms	UAA (ha)	N. of farms	UAA	N. of farms	UAA	N. of farms	UAA	N. of farms	UAA
CATA	130	4012							130	4012
RISP			3	346	2	231	19	2190	24	2766
CATB	40	1275							40	1275
MIX2			50	7320	5	732			55	8053
SHA			35	3041	5	434	5	434	45	3910
CITR			68	857					68	857
MIX1	76	1686	303	6722	163	3616	20	444	562	12468
GRH	35	452	5	65	4	52	2	26	46	594
MIX3					85	496	15	87	100	583

4.2. Sources of agricultural uncertainty from climate variability

Climate variability generates uncertainty for the various crop and livestock activities. For instance, the sustainability of rain-fed cropping activities, that are carried out also in the RIB sub-zone, is constrained by the inter-annual instability of pasture and hay-crop yields, which is closely dependent on climatic factors particularly in the autumn and spring. The pasture growing season starts with season's rainfall break in the autumn, is constrained by low temperature and radiation in the winter and reaches its maximum in the spring, to decrease sharply in quantity and quality at the onset of the summer, when soil water content reaches a minimum. The dairy sheep farming system is adjusted to concentrate lambing in October-November and February, in order to extend the flock milking season from December-January until July. Low Autumn pasture yields would result in increased purchases of feed and forage or the early depletion of hay stocks. Hay stocks are produced in May from a single cut of annual hay-crops (e.g. annual ryegrass and oats, sometimes mixed with legumes) or less frequently meadow grasslands. Again, dairy cattle irrigated forage systems are also affected by climate in terms of variable irrigation needs but also in terms of forage yield, which can also result into higher external feed input demand on bad years.

These effects of climatic variability generate uncertainty on the crop allocation in arable lands. The purchase of feeds or hay, or the increased well water extraction are the most common adaptive responses to bad years in rain-fed and irrigated lands respectively. However, there are other effects of climate variability that are instead difficult to mitigate with corrective actions. This is the case of heat waves with high air humidity levels in the summer, which cause the losses of production of cow's milk, the worsening of its quality levels which results into reduced price, and the increased mortality of cows. Albeit of less dramatic economic impact, also the variability of crop irrigation needs can determine increases in the amount of irrigation fees to cover the extra-costs for RIB water distribution. This distinction in the possibility of mitigating the effects of climate variability will be reflected in the analysis on how the choices of farm management will be simulated.

In the next sections, the climate, crop and livestock models used for simulating climate impacts on production are first described, along with the statistical processing of their outcomes. Then, the modeled impacts of climate change will be illustrated before describing the area economic model. Follows the analysis of the different components of water cost, and of the way in which the latter have been estimated. Finally, the simulated pricing systems and levels of cost recovery for irrigation water are described.

4.3. Climate models and scenarios

The potential climatic forcing that acts on the study area, and the changes due to CO_2 expected future concentration were evaluated with a downscaling strategy to produce calibrated time series of rainfall and temperature over the study region already developed for the AGROSCENARI project (www.agroscenari.it). This strategy builds a modeling chain describing with a high level of reliability the main atmospheric variability that acts on the area, from large scale to local scale; and considering the change in the concentration of greenhouse gases. It applies a coupled model of general circulation to estimate large scale atmospheric and ocean response to future SRES-A1B (Nakicenovic and Swart, 2000) emission scenario as described in Scoccimarro et al. (2011). In this regard, two periods of 11 years were selected: 2000–2010 representing current climate conditions, and 2020–2030 as conditions of near future. For this near future time range the CO_2 concentration of SRES-A1B emission scenario does not differ significantly with respect to the more recent Representative Concentration Pathways (Moss et al., 2010) and the correspondent radiative forcing computed from global models as well. This is because the structural differences between the two sets of emission scenarios are more evident beyond 2050, when the uncertainty about the reliability of projections is greater. The adopted global simulations belong to a specific set developed by the Euro-Mediterranean Center on Climate Change (CMCC - www.cmcc.it) in the framework of the EU project Circe (www.circeproject.eu). The general circulation model drives the Regional Atmospheric Modelling System (RAMS) applied on the study area to increase the physical description of acting mechanism at local scale, and to better represent local variability (Pielke et al., 1992). The proposed RAMS model configuration follows settings as other studies on numerical weather forecast (Meneguzzo et al., 2004). Due to limitations in the geo-morphological representation of numerical models (mountain chains or land cover), significant systematic errors may affect direct outputs of modeling chain atmospheric fields reducing the potential usage for agricultural applications. Such systematic errors were reduced by applying a post-processing procedure based on observed data. To this end the RAMS was also forced with reanalysis dataset: the Reanalysis-2 for the atmospheric component (Kanamitsu et al., 2002), and the reconstructed sea surface temperature from Hadley Centre (Rayner et al., 2003), with the same configuration for current and future scenarios. The direct RAMS model outputs, only forced by reanalysis datasets were compared to surface observed data of the study area for the period 2000-2010. Bias corrections were then computed using a linear regression at daily scale for temperature values, and a quantile-quantile correction for rainfall to reduce typical modelling bias as described in Pasqui et al. (2013). These corrections were then applied to the outputs of RAMS simulations to calibrate current and future climate scenarios, assuming that the geo-morphological source of errors will act independently, since these conditions are inherently steady. Finally, in order to improve the statistical representativeness of the calibrated 11 years' time series of each scenario created with RAMS the WXGEN weather generator (Nicks et al., 1990) was used using the RAMS calibrated scenario summary statistics as input to compute a set of synthetic time series of 150 years, hereinafter called 150 synthetic years, that were then used to run crop model simulations.

Figure 3 represents the average values of maximum and minimum temperatures, and the distribution of precipitations from the synthetic 150-years series of current and future climate.

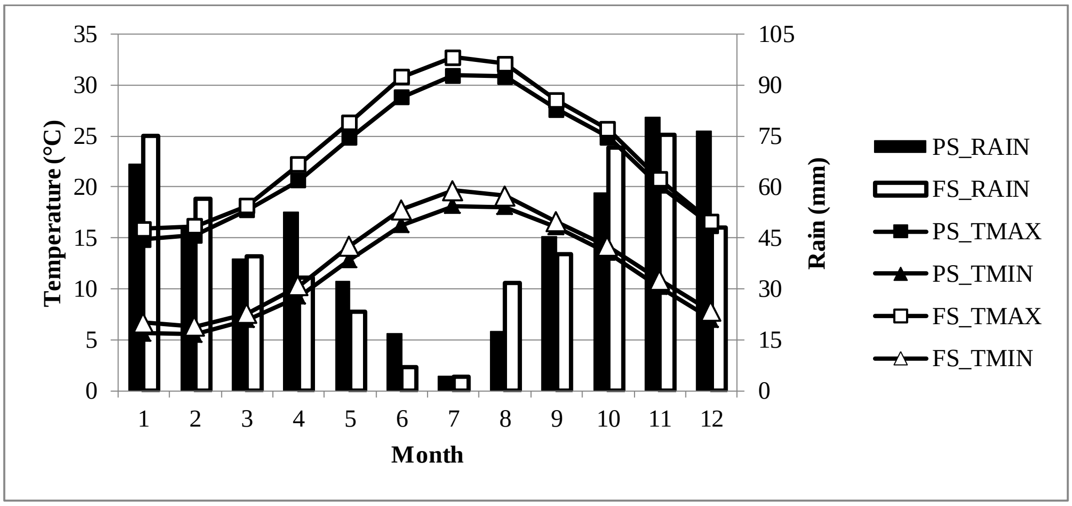

Figure 3. Synthetic 150 years: average values of maximum and minimum temperatures (TMAX, TMIN) and precipitations (RAIN) for current and future scenarios (PS, FS). Source Dono et al. (2016)

The present and future climate scenarios computed with RAMS and WXGEN models represent the basic forcing to drive the productive impact assessment and the economic evaluation. Temperature and precipitation anomalies expected in the near future showed a high seasonal heterogeneity. Both minimum and maximum seasonal mean temperature are expected to increase in all seasons with a stronger signal in the summer. Expected precipitation seasonal mean values changes are negative and weaker in winter and stronger in spring (-33%), while weak positive or absent anomalies are expected respectively for summer and fall. All these future climate change features are aligned with the already observed long term trends during the past 30 years.

4.4. Crop models and agronomic data

Two crop models were used to estimate the influence of temperature, rainfall and atmospheric CO_2 concentration on the main crops of the study area in the two climate scenarios: the EPIC model (Environmental Policy Integrated Climate, v 0810; Williams, 1995) and the DSSAT model (Decision Support System for Agrotechnology Transfer v 4.6; Jones et al., 2003; Hoogenboom et al., 2012). EPIC was widely validated and used for several purposes ranging from the simulation of crops yields (Balkovic et al., 2013; Wang et al., 2005; Cabelguenne et al., 1990) to more complex uses like the assessment of the impact of climate change (Strauss et al., 2012; Niu et al., 2009). DSSAT is used to determine optimum crop management practices (including cultivar, fertilizer, water and tillage), precision agriculture, climate change and variability, long-term sustainability, environmental pollution, and genomics (Jones et al., 2003; Hoogenboom et al., 2012).

EPIC was applied to simulate alfalfa, a silage corn-Italian ryegrass double cropping system based on two corn hybrids with different earliness, widely used in the irrigated sub-area served by the RIB, and rain-fed hay crops and grasslands, very common in the rain-fed sub-area. EPIC was calibrated based on local crops datasets, soil and weather from field trials, or from interviews with farmers in the study area.

Italian ryegrass is cultivated from mid-October to mid-May to produce hay and is occasionally irrigated in case of drought, while the growing season of silage maize is from the end of May till September and is always irrigated. Both crops were simulated using constant sowing dates, while harvest was scheduled based on accumulation of heat units: harvests of silage maize and ryegrass hay were respectively set to 90% and 60% of the units of the total heat required for maturity. Alfalfa was simulated as a 4-year continuous cultivation, and 4-5 mowing from May to September. The irrigated crops were simulated without water and nitrogen stresses, by setting automatic irrigation based on soil water content and automatic fertilization based on plant N stress. In the rain-fed area, grasslands are mainly composed of annual grasses and legumes and grazing occurs all year round. Rain-fed hay crops are based on oats and/or Italian ryegrass annual species, sown in October-November, grazed until mid-February and mowed in May. The hay-crops were simulated with automatic N fertilization, while grasslands were unfertilized. The static soil option was adopted to avoid changes in soil properties that could affect the simulated crop production in the continuous 150 years simulation.

DSSAT was applied to simulate the systems of irrigated rice paddy, and rain-fed winter cereals. Datasets for rice and winter cereals were obtained from surveys, interviews, observations, sample analysis, and from data systematically collected by private farms. The cultivar coefficients of the crops were estimated with the Genetic Coefficient Estimator (Hunt et al., 1993) based on long-term data obtained from private farms. The coefficients of species and ecotype where left unchanged.

Rice is sown in the second half of April and harvested at the end of September, while winter cereals are grown from November to late June. Rice was simulated without water stress by setting automatic irrigation based on soil water content, and using the local business as usual fertilization schedule. Rain-fed winter cereals were simulated with automatic N fertilization option. Constant sowing dates were simulated for both rice and winter cereals, while harvests were scheduled when physiological maturity occurred. Soil properties were kept constant over time.

4.5. Livestock analysis and data

The relationships between climate and animal production in the current and future scenarios were estimated on the basis of the results of studies carried out in Holstein breed, which is widely prevalent in the local dairy district. Attention was focused on the relationships between temperature and humidity, condensed in the temperature humidity index (THI), and the mortality of cattle, the quantity and quality of milk produced.

The links between THI and mortality were studied using the Bovine Spongiform Encephalopathy database provided by the Italian Reference Centre for Animal Encephalopathies (Vitali et al., 2009). The database contained records from 2002-2007 on 51,240 cows older than 24 months, died in 2,291 dairy farms. THI data were related with deaths by associating each farm was to the nearest of 73 weather stations, whose data on temperature and relative humidity were used to calculate THI using the formula of Kelly and Bond (1971). The relationship between THI and milk yield were studied on 596,515 test-day records from 484 dairy farms located throughout Italy and dated from 2001 through 2007 (Bernabucci et al., 2014). Milk yield data were associated to daily THI calculated from data of 35 meteorological stations located within a maximum of 5 km from each farm. The THI-somatic cells relationship study (Bertocchi et al., 2014) was conducted on 508,613 bulk milk tests recorded monthly during the period 2003-2009 in 3,328 dairy farms located in the Po valley. The somatic cells count, expressed as cells/ml, was converted into the somatic cells score (SCS). The SCS values of 5.00 and 4.58, corresponding to 400,000 and 300,000 cells/ml, are the limits for commercialization of *milk cow* and *high quality milk cow*, respectively. Each farm was associated to the nearest weather station and SCS values were associated to daily THI data from 40 weather stations. The relationships between THI, cow mortality, milk yield and SCS were established by a 2-phase linear regression procedure (Nickerson et al., 1989) to detect an inflection point, if one exists, in the relationship between the independent variable (THI) and the dependent variable (mortality, milk yield and SCS).

4.6. Statistical processing of climate, crop and livestock model outputs

As mentioned, the two synthetic 150-years series of daily data that represent the outputs of climate models RAMS and WXGEN were used to feed crop and livestock models that predicted the productive responses to present and future climate scenarios. For its characteristics, the economic model that will be described requires climatic and productive outcomes to be statistically elaborated and introduced as discrete input variables. In particular, these outcomes were used to estimate current and future Probability Distribution Functions (PDFs) of the yields of rain-fed (pastures and grasslands) and irrigated (maize, ryegrass and alfalfa) crops, and of the subsequent irrigation needs of the latter. The PDF of net evapotranspiration (ETN) was used to evaluate the change in irrigation needs of other crops when moving from present to future climate. All PDFs were obtained using the statistical software @Risk® v. 7.5 (Palisade Corporation) with a maximum likelihood estimator. Chi-square tests were applied to identify the function that best approximates the data set. Finally, the range of each PDF was discretized by arbitrarily dividing it into three states, with 25% probability for low and high states, and 50% for intermediate. The arithmetic mean obtained from those synthetic years lying within each state was used as its representative value.

Figure 4 shows as example some of these PDFs, with the solid blue representing the function of the present, and the red line that of the future.

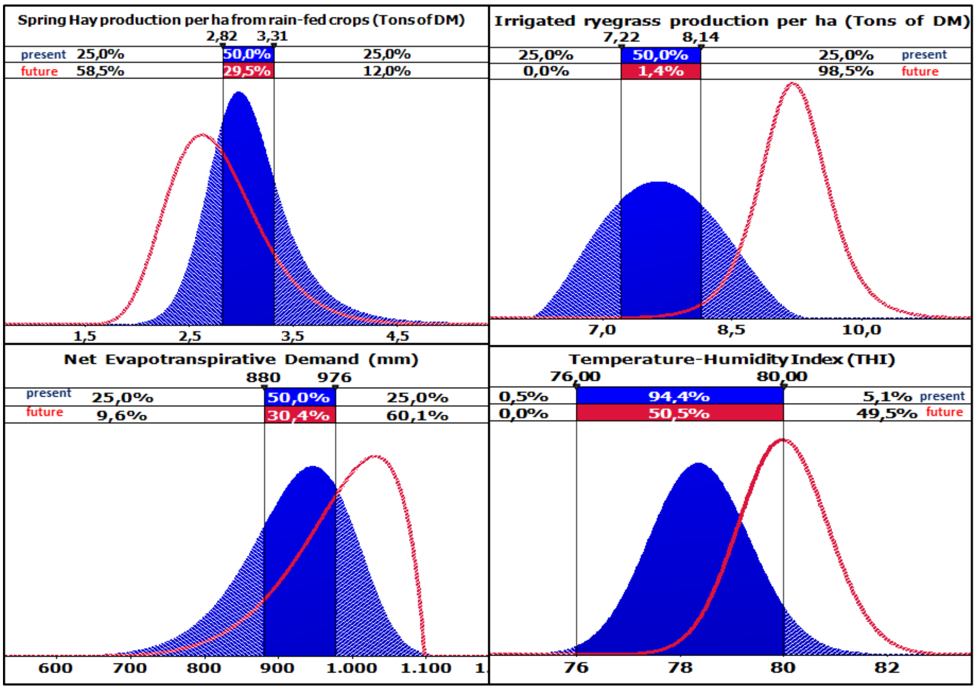

Figure 4. Current and Future PDFs for a) Spring hay yield of rainfed crops, b) Irrigated ryegrass yield, c) ETN from April to August, d) THI (July-August). Source: Dono et al. (2016)

4.7. Modelled impacts of climate change

The first graph reports the PDFs of the dry matter per hectare (DM/Ha) of spring hay from rain-fed crops. The probability of harvesting less than 2.8 t DM ha-1 rises from 25.0% under present climate to 58.5% under future climate. Conversely, the probability of intermediate yields drops from 50.0% to 29.5%, and that of abundant yields drops from

25.0% to 12.0%. This result is the consequence of the expected reduced rainfall and increased temperatures in spring, when the grass growth rate is at its maximum potential, but is constrained by the increased water stress under future climate and rain-fed conditions. These losses occur despite the simulations of the future climate were run under higher atmospheric CO_2 concentration. The second graph shows that removing the water stress by imposing automatic irrigation, this impact of climate change was reversed and the probability of high DM yields for Italian ryegrass increased from 25.0% under present climate to 98.5% under the future climate.

The third graph shows the impact of rising temperatures and reduced rainfall on ETN from the end of spring to early summer, which corresponds to the irrigation season. Note that the increased probability of high irrigation needs shifts from 25.0% to 60.1% when moving from the present to future climate scenario. The opposite happens for the states with lower irrigation needs. The shift of ETN is supposed to proportionally affect irrigation needs of fruit, vegetables and other sale crops. However, this trend is also found for ryegrass, silage maize and alfalfa, whose irrigation needs, and the corresponding PDFs, were directly estimated.

The fourth graph shows the PDFs of THI in July-August, highlighting states of nature that do not depend on the probability of the present, as the other three, but from specific threshold values. In particular, we consider values of THI greater than 76, critical threshold in correspondence of which the quantity of milk per head drops (Bernabucci et al., 2014), and values greater than 80 beyond which negative effects on livestock mortality rate are generated (Vitali et al., 2009). The graph shows that as early as the present there is a very high probability, 99.5%, that the yield of milk per cow in July-August is less than in the rest of the year. This probability persists in the future: 100.0%. Instead, the probability of livestock mortality dramatically increases, going from 5.1% of the present, to 49.5% of the future. Our study also estimated the effect of climate on productive performances of livestock in April-June and in all the other months. It was found that in April-June will increase the chances of having values of THI associated with an appreciable deterioration of the fat content, protein and somatic cell count of milk (the graph is not shown).

Table 3 provides further details on the representative present and future values entered in the model for the different states of nature. These results are to be read from a different perspective from that used for graphs in Figure 4: the probabilities remain constant and the change is reported as +/- % shift of the representative values.

Table 3. Representative (i.e. mean) values for *states of nature* of crop yields, irrigation needs, ET_N and summer THI under present climate, and percentage changes pf future climate vs present (%Δ)

	Crop system		Present climate			Future climate (%Δ)		
			Low	Intermediate	High	Low	Intermediate	High
Yield (t ha^{-1} d.m.)	Grassland (autumn)		0.6	1.1	1.5	-17.1	-5.5	8.1
	Grassland (spring)		0.8	1.0	1.3	-19.3	-11.4	-8.2
	Hay crops	Autumn-winter grazing	0.3	0.7	1.0	22.5	5.1	5.3
		Spring hay cut	2.7	3.4	3.5	-14.7	-20.7	-7.1
	Italian ryegrass (irrigated)		7.8	7.7	7.5	16.4	19.7	23.6
	Alfalfa		14.0	14.1	14.1	-2.1	-1.1	-1.6
	Silage maize (a)		22.1	22.3	22.3	-5.8	-6.9	-7.2
	Silage maize (b)		21.4	21.6	21.6	4.5	2.6	2.8
Irrigation needs (mm)	Italian ryegrass		101	126	139	44.2	38.1	40.3
	Alfalfa		621	657	660	3.9	3.6	5.7
	Silage maize (a)		384	415	428	-7.0	-4.2	-1.4
	Silage maize (b)		391	421	436	1.4	4.2	7.1
ET_N (mm)			599	650	688	0.0	4.2	4.1

Source: Dono et al. (2016)

In this perspective, notice the forecasted increase in the high state of the autumn pasture yield, due to higher temperature and rainfall in October. The situation of rain-fed grasslands and of hay-crops under rain-fed conditions is opposite in spring, when representative values decrease sharply because of water constraints. On the contrary, Italian ryegrass yields, without water constraints, respond very positively to the CO_2 and temperature rise under future climate. However, this is possible at the cost of a more than proportional increase of irrigation volumes, resulting into the drop in irrigation water use efficiency. Alfalfa irrigation needs are also greater because of higher summer temperatures. The same applies to fruits and vegetables, whose irrigation needs in the future increase in proportion to ETN. The crop cycle duration under future climate is reduced for silage maize. However, maize yields and irrigation needs are reduced for the hybrid currently in use and increase for the hybrid with longer cycle, which could in this way represent a viable adaptation option.

As regards crops and productive performances of livestock that are not modelled with DSP, higher temperatures and atmospheric CO_2 concentrations of the future increase average yields of rice (7.7%), reduce yields of barley(-0.8%), maintain constant yields of durum wheat (+0.1%). The estimates on milk production indicate an annual reduction of 2%. This is due to decreases in July-August ranging from 9.1% to 10.3%, depending on the composition of the herd of the two farm types representing the dairy cattle sector. In addition, there is an average annual reduction of 0.3% in the price of milk that is due to the deteriorating quality in April-June, which reduces 3.8% the related payments.

4.8. Description of the economic model

A DSP economic model was used to represent the farmer's decision-making under the risk conditions generated by weather variability. In this decision-making process, some variables are uncertain when farmer plans the seasonal activity: they occur in succeeding months (stages), when can take different values (states of nature) that affect differently the next steps, and the productive results. So, when planning, farmer can only assign a probability to each state, and define corrective actions to continue at best the production activity in the various cases. According to the DSP, farmer plans the activity based on the state with the highest expected income, calculated on its optimal and suboptimal results. The optimal result is achieved if planning is based on a state of nature, and it really occurs; suboptimal results happen when other states occur. To plan considering the chance of suboptimal results leads to precautionary choices, resulting in an lower income than that would have occurred in a context of certainty, that considers only the optimal solution. This cost of uncertainty may increase if the CC modifies the probability, or the representative values of the various states: so, the impacts of CC can be evaluated by comparing the results of the DSP model under present vs. future climate. The DSP model of this study focuses on the role of climate variability in making uncertain several agricultural parameters, water needs of crops among the others. The model is structured in blocks related to the macro-districts and, within them, to the farm types. Equation (1) is the objective function (OF) that maximizes the overall gross margin (ZGM) of farming activity, as sum of gross margins related to each crop (j) and livestock activity in all the farm types (ty) operating in the macro-districts (d) of the whole *Oristanese* area . It can be defined as follows:

$$\max_{x_{1\,j,d,ty},\, xr_{n_{s,d,ty}}} Z_{GM} = \sum_{j,d,ty} \left(gi_{j,d,ty}\, x_{1\;j,d,ty} - \sum_{n=2}^{N} \sum_{s=1}^{S} P_s\, Cr_{d,ty}\, xr_{n_{s,d,ty}} + Pm_{d,ty}\, Qm_{d,ty} - WP_{d,ty} \right) \quad (1)$$

subject to the constraints:

$$\sum_{j} a_{j,d,ty}\, x_{1\;j,d,ty} \leq b_{d,ty} \qquad \forall\; d, ty \qquad (2)$$

$$\sum_{j} a_{s,j,d,ty}\, x_{1\;j,d,ty} \leq b_{d,ty} + \sum_{n=2}^{N} xr_{n_{s,d,ty}} \qquad \forall\, d, ty, s \qquad (3)$$

$$\sum_{j} nutr_j\; y_{s,j}\, x_{1\;j,d,ty} + \sum_{n=2}^{N} xr_{n_{s,d,ty}} \geq r_{d,ty} \qquad \forall\, d, ty, s \qquad (4)$$

$$x_{1\;j,d,ty} \geq 0 \; and \; xr_{n_{s,d,ty}} \geq 0 \qquad \forall\, d, ty, s \qquad (5)$$

$gi_{j,d,ty}$ are the gross margins of the annual cropping activities, whose acreage is chosen in the first stage ($x_{1\;j,d,ty}$); *n* is the number of *stages* of the decision making; *s* are the *states of nature* that uncertain variables can assume; P_s are the probabilities of occurrence of each *state of nature* in the subsequent stages (*n* = 2,..,*N*), which, if not expected, make it necessary to undertake corrective actions ($xr_{n_{s,d,ty}}$) with a unitary cost ($Cr_{d,ty}$); $Pm_{d,ty}$ and

$Qm_{d,ty}$ are, respectively, the unitary price and total quantity of cow and sheep milk; $WP_{d,ty}$ relates to irrigation water pricing, estimated in different ways in the various pricing scenarios and charged to the farm typologies operating in a given *macro-district* of the RIB. We present the various systems applied in the simulated scenarios in a next section. Equations 2-5 are the constraints. In (2) $a_{j,d,ty}$ is the unitary land and labour needs for each activity; $b_{d,ty}$ is the respective availability. Constraint (3) by $a_{s,j,d,ty}$ expresses irrigation needs: this represents uncertainty by considering the diverse needs in the various *states of nature*. Depending on the *state* that occurs in the second *stage*, their sum could exceed the availability of water from RIB ($b_{d,ty}$): in that case, additional water has to be integrated from wells ($xr_{n_{s,d,ty}}$). Constraint (4) refers to animal feeding: $nutr_j$ are the unitary contributions in nutritional elements of fodder crops, $y_{s,j}$ is their unitary yield, whose amount depends on the actually occurring *state of nature*: some of them depress fodder crop productivity, and, given the overall nutrient requirements, additional purchased feed ($xr_{n_{s,d,ty}}$) is needed in the following *stages*. The positivity constraint (5) concerns the levels of cropping activities ($x_{1\ j,d,ty}$) and the intensity of the corrective actions performed ($xr_{n_{s,d,ty}}$).

4.9. Components of irrigation water cost

This model has been applied first to the data of the current climate scenario, then to the data of the future; the effects of CC were deduced by comparing the outcomes of the two runs. In this context simulations were performed on different levels of recovery of water costs by employing various agricultural water pricing systems under the two climate scenarios and comparing the respective results. The recovery of costs with the agricultural water tariffs concerns the costs incurred by the *Oristanese* RIB [hereinafter: Water Distribution Costs (WDC)] and by the ENAS, the Agency that manages the Sardinian water systems and provides water to end-users, agricultural, industrial and civil users [hereinafter: Water Authority Costs (WAC)].

The WDC in the single *macrodistricts* is a function of the amount of water distributed with the technologies equipping that *macrodistrict*. This amount can vary, even significantly, depending on farmers' adjustments in response to the variation of water payments, imposed by changing the pricing system and the level of cost recovery, and by climate change. Hence, also WDC modifies consequently. The latter includes maintenance and management of the irrigation network, from dam to farms, and actual water distribution costs. Depreciation of the distribution facilities is not charged because their construction was publicly funded. In this study, the WDC is estimated using a transcendental logarithmic function (*Translog*) based on prices and amount of energy and labour inputs, amount of distributed water, and technological characteristics of the various districts of the network (Giraldo et al, 2014). Being estimated on observed data, this cost function represents the actual cost operating condition of the *Oristanese* RIB. It can be expressed in general terms as:

$$lnC(z) = \alpha_0 + \sum \alpha_i \ln(z_i) + \frac{1}{2} \sum_i \sum_k \alpha_{ik} \ln(z_i) \ln(z_k) \ , \alpha_{ik} = \alpha_{ki} \qquad (6)$$

This form expresses the logarithm of the WDC (C) in each *macrodistrict* of the RIB as a function of the independent variables z_i and z_k, in our case irrigated acreage (X_{jirr}), watering intensity (W_{irr}) and, in *GR*, network losses (W_{loss}). The coefficients α_i and α_k, and the α_0 constant term, have distinct values in the districts at high pressure, low pressure and gravity. The α_i represent the cost elasticity of the independent variable, hence, their relative importance in generating the WDC. Giraldo et al (2014) show that the irrigated acreage variable largely prevails over irrigation intensity and the network losses in determining the WDC.

In Table 4 is reported, for the single *macrodistricts* and for the entire RIB, the variation of WDC achievable by unitarily increasing the value of a single variable and keeping fixed that of the other two.

Table 4. Sensitivity analysis of the *Translog* function to its components

	Baseline WDC (.000 €)	+1% Xjirr	+1% Wirr	+1% Wloss
			Δ% WDC	
HPAr	1,700	1.08	-0.03	0.00
HPot	903	1.01	0.09	0.00
LP	868	1.28	0.71	0.00
GR	54	1.89	0.55	-1.62
RIB	3,525	1.12	0.19	-0.02

In all the *macrodistricts* appears evident the major percentage contribution of the irrigated acreage in determining the variation of WDC. This is particularly noticeable in *HP*, because of the greater impact of the costs related to the energy component. Here, the weight of average watering intensity is very small, while in *LP* and *GR* it is more relevant. Network losses play a not secondary role in *GR*, although nearly negligible at *RIB* level.

The current pricing in the present (baseline) provides a partial recovery of these costs: a regional subsidy compensates the higher hydraulic lifting energy costs of RIBs due to unfavourable orography and climate of Sardinia.

The WAC is incurred by ENAS for managing, maintaining and developing dams and primary water infrastructures. This cost includes also environmental and resource components . (ENAS, 2010). ENAS evaluates the resource stored in the dams, assigns volumes to industry, households and agriculture, and defines the plan to recover the costs of supplying them water. To this end, ENAS subtracts from these costs the regional subsidies on the energy costs, as well as other revenue sources, such as the sale of hydropower energy. The remaining cost is then divided for the amount of water that can be distributed to end users[1] to get the tariff that should ensure full cost recovery. Finally, ENAS modulates this tariff among end-users to balance possible social and economic impacts of cost recovery. The burden is reduced on households and, noticeably, on farms: indeed, in 2009-2014, compared with an average of 0.046 €/mc, industry paid 0.23 €/mc, families were at 0.04 €/mc and farms at 0.007 €/mc. Industry pays higher fees because is considered predominant in determining resource and environmental costs (RAS, 2009). Therefore, this measure transfers part of the agricultural water cost to other users of the resource and the public service, while the subsidy to extra energy costs transfers them to the taxpayers.

4.10. Pricing systems and cost recovery scenarios

The pricing systems considered in the simulation phase are the following.

- *Acreage Crop* (ACC). The currently applied system charges each irrigated hectare based on two indicators that reflect the water needs of crops, and the benefit generated by the distribution scheme. Its implementation requires the RIB to verify the crops that farmers actually grow.

- *Irrigated Acreage + Watering* (IAW). This simulation incorporates the WDC function in the objective function of the DSP model and directly binds water payments to irrigated acreage extension, watering needs of crops and water losses, as estimated to generate the RIB's WDC (Giraldo et al, 2014). Also, a constant tariff element per used cubic meter considers the payment to ENAS for WAC. This system represents the best result obtainable by making farmers pay according to irrigation need of crops and extension of the irrigated area, as well as making them aware of the impact of their choices on WDC formation.

[1] The water that can be distributed to end users is given by the difference between the water available and the one released downstream of the dams to protect the instream flow.

- *Volumetric* (VOL). This method debits to farmers only according to the used volume of water and ignores the extension of the irrigated acreage in generating the WDC. Its implementation requires an accurate metering that can generate significant costs of investment and measurement to the RIB. Yet, this system is considered the most consistent with the guidelines of the WFD about using the pricing to direct towards the efficient use of water.

- *Irrigable acreage* (IRA). Farm payment is fixed, it is based on the acreage served by the RIB facilities and is independent from the actual use of water: the total WDC is divided among farms based on the parameters that in the current pricing reflect the benefit generated by the water distribution technology. This system is totally opposite to the principles of WFD, but represents for the RIB the less expensive and easiest way to implement and manage, because it does not even require verifying whether or not farmers irrigate. Conversely, it does not generate any economic incentive to evaluate even the opportunity to use or not the water resource.

Each pricing system has been simulated at different levels of cost recovery [*CrL*].

Table 5 shows in detail the various components of the total cost of water supplied by the RIB. The individual items are computed with reference to the unitary values set in ENAS (2010) applied to baseline RIB water volumes (114.6 Mm^3). ENAS agricultural payment is calculated according to the unitary payments set by the ENAS for the agricultural sector: 0.005 €/m3 for RIB water volumes up to 112 Mm^3 and 0.015 €/m3 for the volumes exceeding this threshold. Environmental cost is obtained by the difference between the unitary payment computed by ENAS accounting for the cost of maintaining the minimum vital flow after the withdrawal (0.0461 €/m^3) and without accounting for it (0.0422 €/m^3). Resource cost is computed by subtracting the environmental component and the ENAS agricultural payment to the ENAS payment at the un-modulated fee of 0.0461 €/m^3. Total

RIB's WDC is splitted into two components: one actually covered by agricultural payments and another covered by Regional contribution for the extra energy costs incurred as a consequence of local orographic and climatic disadvantages.

Table 5: WDC components at the baseline - total value (000€), unit value €/m^3, percentage weight over the total (%), paying subjects

Component	**Costs**			**Payer**
	.000 €	€/m^3	%	
Resource cost	4,239.0	0.037	48.1	Industrial sector
Environmental cost	447.2	0.004	5.1	
ENAS agricultural payment	600.0	0.005	6.8	Taxpayers
RIB's WDC - *extra energy cost*	1,382.9	0.012	15.7	
RIB's WDC	2,143.8	0.019	24.3	Farmers
TOTAL	**8,813.0**	**0.077**	**100.0**	

The cost recovery levels [*CrL*] are the following:

• *CrL1*: partial coverage of RIB's WDC, and no coverage of ENAS modulated agricultural rate. Agricultural end-users pay only part of the operative costs of the RIB; WAC incurred in supplying water to the RIB, and environmental and resource costs are not charged. As a consequence, under *CrL1* farmers' payments cover 24.3% of total water cost.

• *CrL2*: partial coverage of RIB's WDC, and FCR of WAC at ENAS modulated agricultural rate. The Regional Authority pays the extra-energy costs incurred by the RIB for water distribution; farmers are asked to cover WAC, that include the environmental and resource modules, at a rate calibrated according to article 9 of the WFD. In this case, the level of cost recovery increases at 31.1%

• *CrL3*: FCR of RIB's WDC and of modulated agricultural rate for WAC recovery. This level of cost recovery is the one that most accomplishes to the WFD, being the costs for water use fully charged to end-users, with regard also to the provisions of article 9. The level of cost recovery reaches 46.8%.

- *CrL4*: FCR of RIB's WDC and of not modulated agricultural rate for WAC recovery (0.0461 €/mc). This level of cost recovery goes beyond the WFD requirements not considering the modulation of cost recovery allowed by article 9: this is likely to generate heavily negative social and economic repercussions.

CrL1 in the current climate scenario is the baseline. The water rates were increased in the same proportion in each of the macro-districts of RIB to achieve higher levels of cost recovery at RIB scale in *CrL2*, *CrL3* and *CrL4*. In particular, in each RIB macro-district the some proportional increase was applied to: per hectare charge of each crop in ACC; extent of irrigated surface and amount of water supplied per hectare, as required by the cultivated crops, in IAW; water use in VOL; acreage served by the RIB facilities in IRA.

The DSP model performs all these simulations with both the present and future climate scenarios: comparing the results will indicate the possible effects of various tariffs under the future climate.

5. RESULTS

The impacts expected from changing the pricing system and the level of cost recovery are shown under current and future climate scenarios. The presentation of the results is articulated to show different, but complementary aspects when accounting for the entire RIB area (Area-level impacts) or for the single *macrodistricts* that compose it (*Macrodistrict*-level impacts).

In each of the following tables, the impacts of the different simulations on the variables considered are expressed as percentage changes over the absolute values of *[crl1]* 2000-

2010 ACC, that represents the baseline and is reported in the first row of the 2000-2010 tables.

5.1. Area-level impacts

5.1.1. Variation in the amount of the unitary water payments

The following Table 6 reports the percentage changes in water payments applied for the various pricing system and cost recovery scenarios, under current and future climate.

Table 6. Baseline amount of unitary water payment (absolute value) and percentage variations under the various pricing systems and levels of cost recovery in the 2000-2010 and 2020-2030 climate scenarios

Climate scenario	*Cost recovery level*	*ACC*	*IAW*	*VOL*	*IRA*
2000-2010	*[crl1]*	0.019 €	-1.3	0.8	0.6
	[crl2]	27.4	25.3	28.1	28.7
	[crl3]	91.2	84.7	93.6	93.6
	[crl4]	310.5	295.8	311.2	312.1
2020-2030	*[crl1]*	0.2	-0.2	0.7	0.7
	[crl2]	28.3	27.3	29.1	29.3
	[crl3]	91.3	88.2	92.7	93.9
	[crl4]	306.5	299.8	312.6	311.3

Modifying the only pricing system (*[crl1]*) involves very limited variations in the unitary payments, while increasing the level of cost recovery determines strong increases of payments, even dramatic in *[crl4]*. Differences, although not huge, exist between the two climate scenarios. Looking at the pricing systems, in the present scenario and partly in the future, *IAW* requires to impose smaller percentage increases in payments to obtain the same degree of coverage as other pricing systems. This happens because this pricing operates considering both the acreage of irrigated land and the intensity of watering, thus fully accounting for the components that contribute to determine water cost. Conversely, the fixed cost per hectare mechanism, *IRA*, which does not stimulate a change in the use of water resources, requires the highest increases to be applied.

5.1.2. Changes in cropping schemes

Table 7 shows the modifications of area cropping mix that occur under the current climate when modifying the pricing system and the level of cost recovery.

Table 7. Impacts expected on the cropping schemes in the RIB area under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		Durum Wheat	Rice	Hay Crops	Silage Maize	Italian Ryegrass	Alfalfa	Field Horticultural Crops	Greenhouse Horticultural Crops
[crl1] – ha	*ACC*	6576	2700	4226	5711	3557	1831	5704	385
Δ % on *ACC* [crl1]									
[crl1]	*IAW*	0.5	-0.5	0.1	0.7	-6.7	-0.5	-0.8	-1.9
	VOL	0.6	-1.9	0.1	-1.7	3.0	-6.4	-0.8	0.6
	IRA	0.0	0.4	0.0	-0.2	3.1	-2.3	-0.1	-0.3
[crl2]	*ACC*	0.9	-1.3	1.5	-0.8	-1.4	-1.2	-0.3	-0.3
	IAW	1.0	-1.0	0.2	0.8	-10.6	-1.0	-1.2	-2.8
	VOL	1.5	-3.0	0.3	-2.5	1.7	-8.7	-1.3	0.5
	IRA	0.0	0.4	0.0	0.3	3.1	-2.3	-0.1	-0.3
[crl3]	*ACC*	3.0	-4.2	4.1	-2.6	-4.5	-4.0	-1.1	-1.1
	IAW	2.7	-2.6	0.6	-0.2	-19.0	-3.9	-2.9	-4.7
	VOL	3.6	-5.7	0.9	-4.5	-1.3	-14.4	-2.3	0.1
	IRA	0.0	0.4	0.0	-0.2	3.1	-2.3	-0.1	-0.3
[crl4]	*ACC*	9.4	-14.3	14.1	-10.0	-13.0	-15.9	-5.0	-3.9
	IAW	8.3	-7.7	3.8	-4.9	-36.0	-15.8	-10.8	-10.7
	VOL	9.8	-14.6	9.8	-12.4	-6.4	-37.0	-9.5	-1.6
	IRA	0.0	0.4	0.0	-0.2	3.1	-2.3	-0.1	-0.3

With few exceptions, mainly given by the *IRA* system that removes any link between water use and payment, increasing the level of cost recovery from *[crl1]* to *[crl4]* penalizes irrigated crops and determines, where possible, a substitution effect in favour of the rain-fed ones (durum wheat and hay crops). This effect is generally less evident for field and greenhouse horticultural crops, that are grown in small, but very specialized farms, which would not find possible to replace them with other crops.

With regard to the pricing systems, the *IRA* does not allow a reallocation of water resources and the cropping mix remains unchanged in the various simulations, penalizing alfalfa and favouring Italian ryegrass. The former is penalized by any increase of the level of cost recovery in particular under the *VOL* system, because of its narrow margin of economic convenience and its high water requirements. Although at a lesser extent, however, the *VOL* penalizes also rice and silage maize more than other systems, while has milder or even positive effects on field and greenhouse horticultural crops. On Italian ryegrass the impacts of the *VOL* are positive at the lower levels of cost recovery (*[crl1]* and *[crl2]*), mainly due to its relatively lower water requirements compared to the biomass produced, but these become negative at higher levels. The similarity of the pricing mechanisms underlying to the *IAW* and the *ACC* systems is confirmed by the fact that, with the only exception of the smooth impacts on silage maize in *[crl2]*, they produce effects of the same sign, although of different intensity. More evident appear the negative impacts of the *IAW* on the acreage of the greenhouse crops and, at a dramatic extent, of the Italian ryegrass, that are instead much milder under the *ACC* system. On the contrary, rice and silage maize are strongly penalized by *ACC*, and much less by *IAW*. These uneven impacts can by explained considering that the *ACC* system accounts also for the benefits gained from irrigation, that are the highest in the HP_{Ar} *macrodistrict* where cattle farms growing silage maize operate. Moreover, *ACC* burdens rice at a greater extent than *IAW* because this crop is grown in large and specialized farms that, as will be shown, are characterized by high average NI. On the contrary, the horticultural farms, having lower NI and performing very risky activities, are partly relieved from the burden of irrigation water cost, along with farms that extensively cultivate Italian ryegrass outside the HP_{Ar}. Shifting to *IAW*, this fair mechanism for the modulation of water payments is lost, and the latter come to be computed only accounting for the irrigated acreage and for the watering intensity.

Table 8 reports the changes in cropping mix to be expected under the future climate scenario.

Table 8. Impacts expected on the cropping schemes in the RIB area under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		Durum Wheat	Rice	Hay Crops	Silage Maize	Italian Ryegrass	Alfalfa	Field Horticultural Crops	Greenhouse Horticultural Crops
[crl1]	*ACC*	1.2	1.9	-0.6	5.1	6.9	-26.1	0.8	-0.7
	IAW	1.5	2.1	-1.5	5.6	4.9	-24.6	0.2	-2.6
	VOL	1.5	0.6	-0.9	6.9	9.3	-29.2	0.3	0.0
	IRA	1.0	2.3	-1.6	7.3	8.8	-28.5	0.7	-1.0
[crl2]	*ACC*	1.4	1.6	0.2	4.1	6.7	-26.0	0.6	-1.1
	IAW	2.3	1.5	-1.3	4.8	3.4	-24.1	-0.4	-3.5
	VOL	2.0	-0.2	-0.1	5.3	9.6	-30.2	-0.1	-0.1
	IRA	1.0	2.3	-1.6	7.3	8.8	-28.5	0.7	-1.0
[crl3]	*ACC*	2.5	0.7	2.1	1.8	5.6	-26.7	-0.1	-1.9
	IAW	3.4	0.2	-0.3	2.1	1.1	-24.2	-2.8	-5.5
	VOL	3.7	-2.6	2.4	-0.6	10.2	-33.8	-1.7	-0.4
	IRA	1.0	2.3	-1.6	7.3	8.8	-28.5	0.7	-1.0
[crl4]	*ACC*	6.9	-4.9	18.4	-19.3	7.5	-39.0	-5.5	-4.7
	IAW	9.2	-5.0	8.2	-9.0	-9.0	-27.2	-10.8	-11.4
	VOL	9.0	-12.2	18.2	-25.2	16.1	-54.0	-9.7	-2.0
	IRA	1.0	2.3	-1.6	7.3	8.8	-28.5	0.7	-1.0

In the future, CC is expected to determine positive yield impacts for durum wheat, rice, silage maize and Italian ryegrass, counteracted by yield losses for hay crops and, particularly, alfalfa, as shown in Dono et al. (2016). Yield variations determine the extent of the impacts in *[crl1]* 2020-2030 *ACC*, where the pricing system and the level of cost recovery are kept unchanged respect to the baseline. Nevertheless, these variations play a role under the alternative scenarios, determining different impacts from those described in Table 7.

When increasing the level of cost recovery, the substitution effect of the irrigated crops with the rain-fed is now well differentiated between durum wheat, that is generally favoured, and hay crops, that at least up to *[crl3]* are disadvantaged by the lower yields. Irrigated yield-gaining crops, such as rice, silage maize and Italian ryegrass, benefit from yield increases that generally allow greater acreage increases up to *[crl3]* and smoother acreage decreases (or even further increases in the case of Italian ryegrass) in *[crl4]*, despite the growing costs for irrigation. CC also increases the magnitude of the negative impacts on alfalfa produced when changing the pricing system and increasing the level of cost recovery. However, the mutual relationships among the different pricing systems are expected to not substantially be overturned under the future climate. The very small amount of variations projected for field and greenhouse horticultural crops is due to the fact that yield impacts for these crops have not been simulated.

5.1.3. Modification of area use of inputs

Table 9 shows the area use of inputs (surface water [SW], groundwater [GW], family labour [FAM], external labour [EXT], Nitrogen and purchased feeds) under the alternative pricing systems and levels of cost recovery in the present climate.

Table 9. Expected impact on the use of inputs in the RIB area under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		Water		Labour		Nitrogen	Purchased Feeds
		RIB	GW	FAM	EXT		
		Mm^3		Mh		Tons	
[crl1]	*ACC*	114.6	3.8	3,366	689	8,187	886
Δ % on *ACC* [crl1]							
[crl1]	*IAW*	-0.7	-0.8	-0.2	-1.3	-0.7	1.1
	VOL	-1.4	-0.4	-0.1	-0.8	0.7	0.7
	IRA	0.1	-0.1	0.0	0.1	0.5	-0.6
[crl2]	*ACC*	-1.0	-0.2	-0.1	-0.5	-0.3	1.5
	IAW	-1.2	-1.2	-0.3	-2.1	-1.2	2.1
	VOL	-2.3	-0.8	-0.2	-1.5	0.5	1.6
	IRA	0.1	-0.1	0.0	0.2	0.5	-0.9
[crl3]	*ACC*	-3.1	-0.8	-0.3	-1.8	-1.0	4.3
	IAW	-3.2	-2.4	-0.7	-4.4	-2.6	4.5
	VOL	-4.5	-1.6	-0.5	-3.2	0.1	3.9
	IRA	0.1	-0.1	0.0	0.1	0.5	-0.6
[crl4]	*ACC*	-11.0	-3.1	-1.3	-6.5	-3.8	15.2
	IAW	-10.4	-6.8	-2.3	-12.1	-7.2	10.6
	VOL	-13.8	-5.2	-2.1	-9.8	-2.9	14.3
	IRA	0.1	-0.1	0.0	0.1	0.5	-0.6

Regardless of the pricing adopted, with the exception of the *IRA* system, increasing the level of cost recovery leads to progressively stronger reductions in the use of RIB water (along with the other inputs, apart from feeds). However, these are not counteracted by an increase of groundwater withdrawals. At first sight, this appears in contrast with the warnings of other Authors (Dono et al., 2010;), who include aquifer depletion among the possible shortcomings of the WFD application. Yet, in the specific context of the *Oristanese* area, farms are currently not equipped with a sufficient number of wells for effectively replacing RIB water, nor massively digging new wells will be allowed in the future by local Authorities for realistic environmental concerns. As a result, increasing water payments leads to a generalized reduction of cropping intensity. In the case of dairy cattle and sheep breeding farms this translates into an increase of feed purchase on the market (with higher costs of production), while in the other cases involves reductions in revenues from crop sales.

Looking at the single pricing systems, *IAW* determines the most equilibrate decrease in cropping intensity, with a similar reduction in water use and in nitrogen intake, thus better contributing to reach the environmental objectives of the WFD. However, it determines also the worst impact on labour, reducing in particular the external component in an area in which agriculture represents an important source of employment. The negative impact on labour is best mitigated by the current *ACC* system, which in any case allows appreciable reductions in water and nitrogen use. On the contrary, the *VOL* system induces important imbalances, as it minimizes RIB water use (less than proportionally to groundwater, if compared with *IAW*), but induces the replacement of water-demanding with nitrogen-demanding crops, in effect jeopardizing the achievement of environmental goals, as well as generating negative repercussions on employment.

The following Table 10 reports the impacts under the 2020-2030 climate scenario.

Table 10. Expected impact on the use of inputs in the RIB area under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		Water		Labour		Nitrogen	Purchased Feeds
		RIB	GW	FAM	EXT		
[crl1]	*ACC*	1.7	0.0	0.1	-0.7	2.0	-1.0
	IAW	1.7	-0.7	0.0	-1.6	1.7	-1.1
	VOL	1.3	-0.3	-0.1	-0.9	2.4	-2.5
	IRA	2.1	0.0	0.0	-0.3	2.6	-3.3
[crl2]	*ACC*	1.3	-0.2	0.0	-1.1	1.7	-0.1
	IAW	1.1	-1.2	-0.1	-2.4	1.2	-0.5
	VOL	0.5	-0.7	-0.1	-1.6	2.3	-1.1
	IRA	2.1	0.0	0.0	-0.3	2.6	-3.3
[crl3]	*ACC*	0.1	-0.8	-0.2	-2.1	1.1	2.2
	IAW	-0.8	-2.5	-0.5	-4.6	-0.2	2.0
	VOL	-2.1	-1.6	-0.4	-3.6	1.6	3.8
	IRA	2.1	0.0	0.0	-0.3	2.6	-3.3
[crl4]	*ACC*	-9.3	-3.4	-1.3	-7.9	-4.0	30.2
	IAW	-8.6	-6.8	-1.9	-11.9	-5.3	14.3
	VOL	-14.2	-5.3	-1.8	-11.8	-2.7	30.9
	IRA	2.1	0.0	0.0	-0.3	2.6	-3.3

The above-mentioned yield increases for major irrigated crops under CC generate a parallel increase in the use of RIB water and nitrogen, as evidenced in *[crl1]* 2020-2030 *ACC*. This has generally negative effects, hampering significant reductions in resource use up to *[crl3]*, worsening the negative impacts on labour employment and dramatically boosting the purchase of feeds, in particular under *[crl4]*.

Also in this case, the different pricing systems remain in the same mutual relationships as those described for the 2000-2010 scenario.

5.1.4. Impacts on Net Incomes of the farm typologies

Table 11 reports the impacts on NI in the 2000-2010 scenario. The absolute values of the baseline refer to the average farm income of the types, and are arranged in descending order.

Table 11. Impacts expected on the NI of the single farm typologies under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		*CATA*	*RISP*	*CATB*	*MIX2*	*SHA*	*CITR*	*MIX1*	*GRH*	*MIX3*
[crl1] 000€	*ACC*	208.6	181.0	164.9	86.8	50.9	40.2	34.1	26.2	10.7
Δ % on *ACC* [crl1]										
[crl1]	*IAW*	0.4	3.2	0.4	-0.3	-0.2	-0.4	-1.1	-0.8	-0.2
	VOL	0.3	3.3	0.3	-0.2	-0.2	-0.4	-1.1	-0.9	-0.2
	IRA	1.0	2.9	1.5	-4.7	-2.1	-0.5	-1.0	-0.8	-1.4
[crl2]	*ACC*	-0.8	-1.4	-1.1	-1.0	-0.4	-0.5	-0.8	-0.9	-0.3
	IAW	-0.3	2.7	-0.6	-1.4	-0.6	-1.0	-2.2	-1.9	-0.6
	VOL	-0.4	2.8	-0.7	-1.3	-0.6	-1.0	-2.2	-2.1	-0.6
	IRA	0.5	2.2	0.8	-7.1	-3.2	-1.1	-2.1	-2.0	-2.1
[crl3]	*ACC*	-2.6	-4.7	-3.8	-3.3	-1.4	-1.6	-2.6	-3.0	-1.1
	IAW	-1.9	1.7	-2.9	-3.9	-1.6	-2.3	-4.7	-4.4	-1.5
	VOL	-2.1	1.8	-3.3	-3.7	-1.7	-2.5	-4.8	-4.9	-1.4
	IRA	-0.8	0.7	-0.9	-12.5	-5.6	-2.6	-4.5	-4.7	-3.7
[crl4]	*ACC*	-8.5	-15.4	-12.4	-9.8	-4.1	-5.3	-8.6	-10.2	-3.7
	IAW	-7.4	-1.2	-11.3	-11.5	-4.6	-7.3	-13.2	-13.6	-4.6
	VOL	-7.6	-0.8	-11.7	-9.9	-4.7	-7.8	-13.5	-14.4	-4.5
	IRA	-4.9	-4.5	-6.7	-30.9	-13.7	-7.5	-12.8	-13.8	-9.3

Results in *[CrL1]* show that modifying the pricing system at the current level of recovery may generate a certain, sometimes relevant, heterogeneity of income impacts on the single types. Yet, in all the simulations, the types with higher NI (*CATA*, *CATB* and *RISP*) improve their condition, while the other types always lose NI, even notably (-4.7% *MIX2*; -2.1% *SHA*), which may suggest that the current pricing (*ACC*) supports the lower income farms. Starting from *[crl2]*, increases in the cost recovery level generally reduce farm incomes, and gains of the higher NI types gradually narrow and finally become negative. Yet the considerations made in advance remain: ACC allows the lower NI types to face milder impacts, while the opposite happens with the other pricing. The greater redistributive effect is generated by applying the *IRA* fixed fee scheme that does not allow farm decision making to adapt to changes in the cost of using RIB water. Applying *[crl3]* generates appreciable impacts in many cases: -12.5% *MIX2*, -5.6% *SHA*, -4.7% *GRH*. Reaching *[crl4]* generates major impacts (-15.4% *RISP*; -14.4% *GRH*; -13.7% *SHA*), dramatic in some cases (-30.9% *MIX2*).

Table 12 reports the impact on NI of the single farm types in the 2020-2030 scenario.

Table 12. Expected impact on the NI of the single farm typologies under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		*CATA*	*RISP*	*CATB*	*MIX2*	*SHA*	*CITR*	*MIX1*	*GRH*	*MIX3*
[crl1]	*ACC*	-4.8	9.2	-5.7	2.2	-4.8	0.0	-0.9	0.0	0.0
	IAW	-4.4	12.4	-5.3	1.7	-5.0	-0.4	-2.0	-0.9	-0.2
	VOL	-4.5	12.5	-5.5	1.8	-5.0	-0.4	-2.0	-0.9	-0.1
	IRA	-3.8	12.1	-4.1	-2.6	-7.0	-0.5	-1.9	-0.8	-1.4
[crl2]	*ACC*	-5.6	7.7	-6.8	1.1	-5.3	-0.5	-1.7	-1.0	-0.3
	IAW	-5.2	11.9	-6.4	0.5	-5.4	-1.0	-3.1	-2.0	-0.6
	VOL	-5.3	11.9	-6.6	0.7	-5.4	-1.0	-3.1	-2.1	-0.5
	IRA	-4.3	11.4	-4.9	-5.0	-8.1	-1.2	-3.0	-2.0	-2.1
[crl3]	*ACC*	-7.5	4.3	-9.5	-1.2	-6.3	-1.7	-3.5	-3.1	-1.1
	IAW	-6.8	10.7	-8.8	-2.0	-6.5	-2.3	-5.6	-4.7	-1.4
	VOL	-7.1	10.8	-9.2	-1.8	-6.5	-2.4	-5.5	-4.9	-1.3
	IRA	-5.6	9.9	-6.6	-10.6	-10.5	-2.7	-5.5	-4.7	-3.8
[crl4]	*ACC*	-13.7	-8.0	-18.5	-8.5	-9.2	-5.7	-9.8	-10.8	-3.9
	IAW	-12.7	7.5	-17.3	-10.1	-9.5	-7.2	-13.9	-14.0	-4.5
	VOL	-12.9	7.8	-18.1	-9.0	-9.6	-7.8	-14.4	-15.2	-4.5
	IRA	-9.8	4.6	-12.5	-29.4	-18.8	-7.6	-13.9	-13.9	-9.4

First, it is worth to notice the positive impact of CC on some farm types (+9.2% RISP, +2.2% MIX2), and the negative impact for others (-5.7% CATB, -4.8% CATA and SHA). Modifying the only pricing system in *[crl1]* creates an additive effect of the two impacts and does not change the relative position of the farms. Yet, the basic effect of abandoning the *ACC* does not change: the loss of indirect support for lower-income farm types, as also under the current climate. Furthermore, some interesting cases are generated, such as the loss of MIX2 climate advantage with the transition to *IRA*. The relative position of farms does not change by progressively increasing the level of cost recovery; however, some negative combined impacts become very high even at the level *[crl2]*. Finally, large rice farms always maintain a very high income gap on other farm types even when applying the most radical cost recovery regime *[crl4]*. Particularly in this case leaving unchanged the *ACC* pricing may represent the only way to avoid a dramatic economic drop in the lower NI farm types.

5.2.Macrodistrict-level impacts

The results presented in the following tables allow to understand more in depth, at the level of *macrodistrict*, the impacts exerted by the simulated changes in the pricing system and in the level of cost recovery. This analysis proves crucial, since the various *macrodistricts* in which the irrigation network of the RIB is articulated, as already explained, are different for the structure and the amount of the costs incurred by the RIB to supply water to the farms, in the light of the different technology of distribution. Therefore, uniform variations of the level of cost recovery applied at RIB-level, like those simulated in the present study, produce very uneven variations in unitary water payments among *macrodistricts*, and the same occurs when shifting to alternative pricing systems respect to *ACC*. Moreover, given that the farm types operating in the area are not uniformly distributed in the various *macrodistricts*, not highlighting these differentiated impacts would hinder a complete understanding of the results shown in the previous section.

5.2.1. Variation in the amount of the unitary water payments

Table 13 shows the impacts on the amount of the unitary payments charged in the single *macrodistricts* and in the whole RIB in the 2000-2010 scenario.

Table 13. Impact expected on the amount of the unitary payments in the single *macrodistricts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1] €	*ACC*	0.036	0.020	0.014	0.006	0.019
Δ % on ACC [crl1]						
[crl1]	*IAW*	-9.1	15.8	64.2	-86.0	-1.3
	VOL	-4.5	17.7	62.4	-86.3	0.8
	IRA	-31.0	115.9	-16.0	-58.4	0.6
[crl2]	*ACC*	27.4	27.5	27.7	27.6	27.4
	IAW	15.1	47.8	110.2	-82.1	25.3
	VOL	21.4	50.7	108.4	-82.4	28.1
	IRA	-11.9	176.4	7.5	-46.8	28.7
[crl3]	*ACC*	91.3	90.8	92.0	91.5	91.2
	IAW	69.5	121.9	214.0	-73.1	84.7
	VOL	86.3	133.1	209.1	-73.7	93.6
	IRA	32.8	315.7	61.6	-19.9	93.6
[crl4]	*ACC*	311.9	308.3	313.3	311.5	310.5
	IAW	270.4	401.7	586.3	-39.2	295.8
	VOL	310.0	430.6	580.1	-40.1	311.2
	IRA	183.1	785.9	244.4	70.6	312.1

Looking at the values in the table, immediately stands out the huge, and in some cases dramatic divergence among the variations in the amount of unitary payments that are generated in the different *macrodistricts* in face of a given, also modest, RIB-level variation. Moreover, divergences result greatly widened even in presence of very narrow ranges of variation imposed at RIB-area level, as those existing among different pricing systems at the same level of cost recovery. This is due to the fact that the baseline level of recovery of the WDC incurred by the RIB in each *macrodistrict* is not the same. In the face of a 60.8% of recovery at RIB level, in fact, payments cover 65.6% in HP_{Ar}, 52.1% in HP_{Ot}, 37% in *LP* and 435.3% in *GR*. This fact explains why, for example, even when increasing the level of cost recovery, *GR* is relieved at a large extent from the burden of payments. This happens under all the simulated alternative pricings, apart from the *IRA* in *[crl4]*, as the fixed per-hectare fees of this system are computed to maintain the same mutual relationships among *macrodistricts* in the recovery of WDC as the *ACC*. Always for the same reason, when increasing the level of cost recovery, HP_{Ot} and particularly *LP* incur the highest increases of water payments. Finally, it is worth to highlight that *IAW* and *VOL* produce very similar impacts on the amount of unitary payments, because both these system target water use (exclusively in the case of the second), differently to what happens with the area-based *ACC* and *IRA* systems.

Similar impacts on the amount of the unitary payments have to be expected in the future climate scenario, as evidenced in the next Table 14.

Table 14. Impact expected on the amount of the unitary payments in the single *macrodistricts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1]	*ACC*	2.3	-1.6	-0.6	-0.7	0.2
	IAW	-5.8	13.3	64.1	-86.6	-0.2
	VOL	-2.5	13.5	59.8	-87.0	0.7
	IRA	-30.1	112.4	-16.1	-58.3	0.7
[crl2]	*ACC*	31.1	25.9	27.4	27.3	28.3
	IAW	20.3	45.0	110.0	-82.8	27.3
	VOL	25.4	46.2	105.8	-83.2	29.1
	IRA	-10.3	172.6	7.7	-46.4	29.3
[crl3]	*ACC*	96.2	87.9	90.6	90.5	91.3
	IAW	78.4	117.3	210.7	-74.3	88.2
	VOL	91.8	123.1	198.8	-75.4	92.7
	IRA	34.6	308.8	61.6	-19.6	93.9
[crl4]	*ACC*	336.6	312.3	318.2	319.4	306.5
	IAW	290.5	382.2	568.5	-42.8	299.8
	VOL	340.6	419.6	574.7	-42.5	312.6
	IRA	185.6	767.4	242.7	70.5	311.3

5.2.2. Modification of the water volumes demanded by farmers

Table 15 reports the impacts on the volumes of water distributed by the RIB in the *macrodistricts* in the 2000-2010 climate scenario.

Table 15. Impact expected on the amount of RIB water used in the single *macrodistricts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1] Mm3	*ACC*	30.6	23.8	22.4	37.8	114.6
Δ % on ACC [crl1]						
[crl1]	*IAW*	-0.7	-0.2	-2.2	0.0	-0.7
	VOL	-2.2	-1.6	-2.5	0.0	-1.4
	IRA	-0.4	0.5	0.2	0.0	0.1
[crl2]	*ACC*	-0.9	-1.7	-0.4	-0.9	-1.0
	IAW	-1.3	-1.0	-3.4	0.0	-1.2
	VOL	-3.1	-3.6	-3.8	0.0	-2.3
	IRA	-0.2	0.5	0.2	0.0	0.1
[crl3]	*ACC*	-2.7	-5.4	-1.2	-3.0	-3.1
	IAW	-2.5	-4.4	-8.1	0.0	-3.2
	VOL	-5.2	-8.9	-6.3	0.0	-4.5
	IRA	-0.4	0.5	0.2	0.0	0.1
[crl4]	*ACC*	-9.6	-17.6	-8.8	-9.3	-11.0
	IAW	-6.1	-16.4	-27.7	0.0	-10.4
	VOL	-13.5	-27.4	-22.9	0.0	-13.8
	IRA	-0.4	0.5	0.2	0.0	0.1

As already pointed out at the RIB-area level, increases in the level of cost recovery generally determine reductions of the quantity of water used by farmers. However, the extent of these reductions is less than proportional to the increase in payments because, in agreement with the findings of other Authors (De Fraiture and Perry, 2002), irrigation water demand reveals relatively inelastic to price changes particularly at low price ranges. This has been deemed to limit the effectiveness of water policies which adopt pricing as the only instrument to control the demand (Yang et al., 2003). In fact, the analysis at the level of *macrodistricts* puts in evidence highly different responses, that only in part can be explained by the above described variations in the amount of water payments. Looking at the particular case of *GR*, alternative pricing systems reduce the burden on farms, but this does not translate in an increase of RIB water use as it would be expected under elasticity conditions. This is consistent with the fact that RISP farms are the main type operating in this *macrodistrict*, and rice requires a particular arrangement of the soil for flooding irrigation that prevents its cultivation to be easily extended to other areas. On the contrary, increasing the burden on these farms with *ACC* gradually reduces water use.

Looking more in depth at the single pricing systems and putting in comparison the variations of water use and payments, it first emerges that generally positive variations in water payments induce negative variations in water use, what is consistent with the economic theory. The only exceptions can be found with the *IRA* system (as expected) and, with the other pricing systems, at the lower level of cost recovery, particularly in HP_{Ar}. This fact can be explained considering the low incidence of water payments on the total amount of the variable costs, that does not prove sufficient in *[crl1]* to induce reduction responses. The *VOL* results the system that induces the greatest responsiveness at every level of cost recovery, with the only exception of *LP* in *[crl3]* and *[crl4]*, where *IAW* proves the best. However, despite the fact that *VOL* and *IAW* systems produce very similar variations of payments, the latter proves less effective in inducing reductions in water use. In HP_{Ot}, moreover, this system is outclassed by *ACC*, at all the levels of cost recovery.

The following table 16 reports the changes in water use to be expected under the future climate scenario.

Table 16. Impact expected on the amount of RIB water used in the single *macrodistricts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1]	*ACC*	0.0	3.6	2.0	1.7	1.7
	IAW	0.3	4.3	0.9	1.8	1.7
	VOL	-0.1	2.7	0.6	1.8	1.3
	IRA	0.5	4.5	2.4	1.9	2.1
[crl2]	*ACC*	-0.4	2.5	1.8	1.7	1.3
	IAW	0.2	3.0	-0.9	1.8	1.1
	VOL	-1.0	1.0	-0.5	1.8	0.5
	IRA	0.5	4.5	2.4	1.9	2.1
[crl3]	*ACC*	-1.5	-1.1	1.2	1.6	0.1
	IAW	-0.5	0.0	-6.7	1.8	-0.8
	VOL	-4.1	-3.9	-4.3	1.8	-2.1
	IRA	0.5	4.5	2.4	1.9	2.1
[crl4]	*ACC*	-17.6	-14.0	-8.0	-0.4	-9.3
	IAW	-5.5	-11.7	-26.9	1.8	-8.6
	VOL	-21.1	-22.4	-23.2	1.8	-14.2
	IRA	0.5	4.5	2.4	1.9	2.1

Under CC the increase of unitary crop water requirements for widespread irrigated crops, that in many cases also further expand their acreage as a consequence of yield increases, prevents to achieve relevant reductions in the use of RIB water up to *[crl3]*. This happens in all *macrodistricts* and particularly in *GR*, where the burden increase generated by the *ACC* system almost completely loses its capacity of determining water reductions.

5.2.3. Variation of the unitary WDC

Table 17 reports for the current climate scenario the variations of the unitary WDC in the single *macrodistricts*, as a consequence of the modification of the water volumes supplied.

Table 17. Impact expected on the unitary WDC in the single *macrodistricts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1] €	*ACC*	0.056	0.038	0.039	0.001	0.031
Δ % on ACC [crl1]						
[crl1]	*IAW*	-1.9	-0.7	0.1	0.0	-1.4
	VOL	3.4	1.3	0.3	0.0	1.4
	IRA	1.5	0.0	0.1	0.0	0.7
[crl2]	*ACC*	-0.2	0.2	0.0	0.8	0.0
	IAW	-2.8	-1.0	0.1	0.0	-2.1
	VOL	3.8	1.9	0.4	0.0	1.4
	IRA	1.3	0.0	0.1	0.0	0.6
[crl3]	*ACC*	-0.6	0.7	0.0	2.6	0.0
	IAW	-4.9	-1.1	-0.5	0.0	-4.0
	VOL	4.9	3.7	0.6	0.0	1.4
	IRA	1.5	0.0	0.1	0.0	0.7
[crl4]	*ACC*	-0.8	3.1	-1.3	8.6	-0.3
	IAW	-8.3	-1.3	-4.1	-0.1	-9.2
	VOL	8.6	12.2	-2.0	0.0	0.1
	IRA	1.5	0.0	0.1	0.0	0.7

A reduction in the volume of water distributed by the RIB determines an increase in the unitary cost at which water is distributed, implying that the distribution facilities are currently operating in conditions of underutilization. An exception is allowed by the *IAW* and the *ACC* systems, which share some constitutive similarities and substantially reduce or at least to limit this increase despite the decrease in water usage. This happens because both these systems are quite complex and, directly or indirectly, account for the determinants of water usage and consequently for the actual cost-cutting mechanisms in the single *macrodistricts*. Conversely, more simple systems like the *VOL* and the *IRA* are unable to reach this goal.

In addition, it is worth to note that very consistent reductions of water usage, as those achieved in *[crl4]*, end up to determine reductions of the unitary WDC, instead of increases. This is explainable considering that the increase in water payments is so strong to determine a drastic reduction in the acreage of the main irrigated crops, what leads the WDC (at large extent determined by the irrigated acreage) to reduce anyway.

The following Table 18 reports the variations of the unitary WDC in the future climate scenario.

Table 18. Impact expected on the average WDC in the single *macro-districts* and in the entire RIB under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1]	*ACC*	1.8	-2.7	-0.5	-4.5	-0.3
	IAW	1.1	-3.4	-0.5	-4.4	-0.8
	VOL	2.7	-1.7	-0.3	-4.3	0.3
	IRA	2.6	-2.9	-0.4	-4.3	0.2
[crl2]	*ACC*	1.8	-2.6	-0.5	-4.5	-0.4
	IAW	0.7	-3.5	-0.7	-4.4	-1.2
	VOL	3.4	-1.2	-0.2	-4.3	0.4
	IRA	2.6	-2.9	-0.4	-4.3	0.2
[crl3]	*ACC*	1.8	-2.3	-0.6	-4.6	-0.7
	IAW	0.0	-3.3	-1.7	-4.4	-2.4
	VOL	6.0	0.1	-0.4	-4.3	0.8
	IRA	2.6	-2.9	-0.4	-4.3	0.2
[crl4]	*ACC*	7.2	0.4	-2.7	-3.6	-2.7
	IAW	-1.7	-3.6	-5.0	-4.5	-6.8
	VOL	18.8	8.2	-2.9	-4.4	0.9
	IRA	2.6	-2.9	-0.4	-4.3	0.2

Determining an increase in RIB water use, CC supports a reduction in the unitary WDC that is particularly evident in *GR*, at every level of cost recovery, and for HP_{Ot} and *LP* up to *[crl3]*, thus confirming for this *macrodistricts* the considerations made above about the underutilization of RIB facilities. In the same way, looking at *[crl4]*, appears confirmed that in presence of very strong reductions in water usage, involving equally strong shrinkages of irrigated surfaces, the unitary WDC reduces.

5.2.4. Net Income variations

Table 19 presents the impacts on the NI generated in the single *macrodistricts* in the current climate.

Table 19. Impact expected on the NI of the single *macro-districts* and of the entire RIB under the various pricing systems and levels of cost recovery in the 2000-2010 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1] 000€	*ACC*	36,676	18,913	8,212	5,485	69,286
Δ % on ACC [crl1]						
[crl1]	*IAW*	0.2	-0.4	-2.5	3.7	0.0
	VOL	0.2	-0.4	-2.4	3.7	0.0
	IRA	1.0	-2.9	0.6	2.5	0.0
[crl2]	*ACC*	-0.8	-0.7	-1.1	-1.2	-0.8
	IAW	-0.5	-1.2	-4.2	3.5	-0.8
	VOL	-0.6	-1.2	-4.1	3.5	-0.9
	IRA	0.4	-4.4	-0.3	2.0	-0.9
[crl3]	*ACC*	-2.7	-2.2	-3.6	-3.9	-2.8
	IAW	-2.2	-3.0	-8.1	3.1	-2.7
	VOL	-2.5	-3.1	-7.9	3.2	-2.9
	IRA	-1.0	-7.9	-2.4	0.9	-2.9
[crl4]	*ACC*	-9.0	-7.0	-11.9	-12.7	-9.1
	IAW	-8.3	-9.2	-20.6	1.7	-9.2
	VOL	-8.7	-9.2	-20.2	1.7	-9.4
	IRA	-5.5	-19.7	-9.6	-3.0	-9.7

At both RIB- and *macrodistrict*-level, increasing water payments produces NI reductions. These are accentuated by the relative inelasticity of water demand, that especially at the lower levels of cost recovery prevents relevant adjustments in water use to be made by farmers. The extent of the impacts in response to a unit variation of water payments differs among the *macrodistricts*, being greater in *GR* (where, however, unitary payments reduce and positive impacts occur), and gradually reduce in *LP* and HP_{Ar}, to be minimized in HP_{Ot}. Here, respect to the other *macrodistricts*, the relatively higher elasticity allows a more sensitive reduction of water usage in response to the increase of payments, thus limiting income impacts.

Considering the pricing systems, each of them has its own impact on the single *macrodistricts* that remains the same at every level of cost recovery, depending on the magnitude and the sign of the variations induced in unitary payments. The worst income impact is generated by *ACC* in HP_{Ar} and GR, by *IRA* in HP_{Ot} and by *IAW* in *LP*. The milder, instead, is determined by *IRA* in HP_{Ar} and *LP*, by *ACC* in HP_{Ot} and by *IAW* and *VOL* in *GR*. It is worth to notice that the considerations made analysing area-level results about the potential of the current *ACC* pricing to limit the negative impacts on lower NI farms, by preferentially burdening higher NI typologies, are confirmed also at *macrodistrict*-level. The latter typologies in fact, as evidenced in Table 8, are located in HP_{Ar} (*CATA* and *CATB*) and in *GR* (*RISP*) and are favoured by all the alternative pricing systems, that generate milder or even positive impacts on them. Although also the low NI *GRH* farms are located in HP_{Ar}, these are substantially relieved by the burden assigned to their *macrodistrict* thanks to the affordability of hectare-crop fees for horticultural crops.

The next Table 20 reports the impacts under the future climate scenario.

Table 20. Impact expected on the NI of the single *macro-districts* and of the entire RIB under the various pricing systems and levels of cost recovery in the 2020-2030 climate scenario

Water payment systems and WDC recovery levels		HP_{Ar}	HP_{Ot}	*LP*	*GR*	***RIB***
[crl1]	*ACC*	-4.6	0.0	-1.3	5.8	-2.1
	IAW	-4.3	-0.4	-3.9	9.6	-2.1
	VOL	-4.4	-0.3	-3.7	9.6	-2.1
	IRA	-3.6	-2.9	-0.7	8.3	-2.1
[crl2]	*ACC*	-5.4	-0.7	-2.4	4.6	-3.0
	IAW	-5.1	-1.2	-5.7	9.4	-3.0
	VOL	-5.3	-1.2	-5.5	9.4	-3.0
	IRA	-4.2	-4.5	-1.6	7.8	-3.0
[crl3]	*ACC*	-7.4	-2.2	-4.9	1.8	-5.0
	IAW	-6.9	-3.0	-9.6	9.0	-4.9
	VOL	-7.2	-3.1	-9.1	9.1	-5.0
	IRA	-5.6	-8.0	-3.8	6.6	-5.1
[crl4]	*ACC*	-14.0	-7.5	-13.7	-8.1	-11.7
	IAW	-13.4	-9.2	-21.8	7.6	-11.6
	VOL	-13.7	-9.5	-21.7	7.6	-11.8
	IRA	-10.2	-20.0	-11.1	2.7	-11.9

In the future the effects of CC on crop yields and on dairy milk production overlap to those generated on water usage and payments, determining different impacts on the various *macrodistricts* from those described under the current climate. In HP_{Ar}, the negative impacts of CC on dairy cattle milk yields are sharpened by the increase in unitary payments, determining income losses of nearly 15% in *[crl4]*. In HP_{Ot} unitary water payments undergo a slightly less dramatic increase compared with the present, and this in part limits the negative impacts of CC allowing NI reductions very similar to the present. With some exceptions, in *LP* unitary payments slightly reduce, but differently from HP_{Ot} this does not prove sufficient to limit the adverse impacts of CC, that leads to a generalized loss of income that reaches almost the 22% at the highest level of cost recovery. Finally, in *GR* the drastic reduction of the amount of water payments, which is maintained in the future, coupled with the significant increase in rice yields determines substantial income gains respect to the current climate scenario.

6. DISCUSSIONS

The considerations made so far allow to think to an ideal approach for pricing irrigation water as one able to organically integrate different environmental, economic and social issues. The WFD resolutely stresses on the first, and limits to generically recommend caution in assessing possible negative repercussions on the last two.

The need to adopt policies that ensure a satisfactory availability and quality of water resources for the different uses, including environmental restoration, has been recognized since long time. Also the necessity of limiting freshwater withdrawals and quality depletion due to agriculture, that is the main freshwater employer, has been stressed. However, several Authors have expressed perplexities, or even warnings, about the provisions of the Directive. In particular, they have pointed out on the substantial vagueness of its provisions (Howarth, 2009; Gómez-Limón and Martin-Ortega, 2013), the contradiction existing among some of its objectives, and the consequential difficulty to achieve all them at the same time (Cooper et al, 2014). Even more, basing on a simple economic instrument, as pricing actual water use, to pursue the controversial principle of full recovery of the costs for water services. For instance, in Northern Italy it has been prospected that, in face of slight water savings, strongly negative economic and social impacts might occur (Bazzani et al, 2005). Furthermore, in the Spanish context, it has been highlighted that the already modest reduction of water use achievable in normal years tend to be dissolved just in droughty years, when water becomes limiting and would be necessary to allocate larger volumes to the civil uses.

Among the most significant advances brought by the present analysis is having evidenced that, in the specific context of the *Oristanese* study area, pursuing FCR especially by means of the volumetric pricing leads to ultimately jeopardize the achievement of the same environmental objectives of the WFD, as well as generating relevant and negative impacts in the economic and employment sides.

With regard to this latter aspect, the *Oristanese* RIB is currently adopting the *ACC* pricing system that generates an indirect support to the lower NI farms by embodying social assessments that would not be met by the other tariff systems considered in this study, including the volumetric. Their adoption would have a relatively limited impact on area NI, but would generate redistributive effects among *macrodistricts* and farm types, moreover in favour of the higher NI ones. All this without considering that the current system, although not directly pricing measured water volumes, still accounts for the water requirements of the different crops, but at the same time allows to avoid the high costs of installation, maintenance and reading of water-meters. Even accepting these negative consequences, the introduction of the *VOL* system would allow to achieve only in part the environmental goals set by the Directive, as this system induces important imbalances that minimize RIB water use (among other things, less than proportionally to groundwater compared with other systems), but replacing water-demanding with nitrogen-demanding crops, and at a certain extent generates negative repercussions on employment as well. Moreover, this system would cost as a waiver to the reduction of the average WDC allowed by adopting, for instance, *IAW*, and, compared with *VOL*, also maintaining the *ACC*. This saving would reduce the inefficiencies that are charged to farmers when increasing the level of cost recovery, approaching the condition of water tariffs that only include costs of efficient management (Massarutto, 2007). Resources could be generated that at least partly, and in theory, could balance the redistributive effects of NI among farm typologies (although these are not the strongest under *IAW*) and the heavily negative impacts on labour employment generated by this system. On the other hand, *IAW* appreciably reduces RIB water use and causes a lower environmental pressure, reducing at the largest extent groundwater and nitrogen use. It is worth to highlight that just groundwater and nitrogen saving have to be regarded as the main opportunities offered by the application of the WFD in this area, where the reduction of RIB water usage cannot be considered a prior goal given the current (and possibly future) non-limiting availability of water from this source. Nevertheless, it could be argued that, in a hypothetical condition of limiting availability, the impacts generated by this system would probably become so much heavier to largely outclass its benefits. Finally, the *IRA* system represents the extreme opposite to *VOL* and clearly goes against the provisions of the Directive. The choice of including it among the simulated pricing systems is motivated by the opportunity of underlining how both the removal of the link between water use and cost (occurring under *IRA*) and its extreme strengthening (under *VOL*) generate undesirable impacts. In fact, while the pure and unmediated pricing of actual water volumes induces an unbalanced reduction of cropping intensity with the only aim of minimizing water costs, the IRA pricing prevents farmers' decisional process to optimize water use, inducing a generalized intensification of agricultural activity which produces the highest redistributive effects on NI and makes farms more susceptible to the increase of the level of cost recovery. However, it is worth to highlight that the present study does not account for the implementation and management costs of the various pricing systems, which for the *IRA* are close to zero. Given that the negative economic impact produced by this system is similar to that generated by *VOL*, accounting for these costs probably would even make it more economically viable.

Other achievements concern the impacts that have to be expected when increasing the level of cost recovery. Full debiting *WAC* to farmers at modulated rates would have still limited total income impacts, although significant on some farm types as demonstrated by the social tensions among farmers, RIB, ENAS, and Sardinia Region recently caused by an attempt to implementing it (La Nuova, 2016). Income impacts worsen when increasing the level of cost recovery up to removing Regional subsidies to the RIB for extra-energy costs and abolishing the modulation of ENAS tariffs, what would reduce more than 10% income in many types, to exceed 30% in extreme cases. Even more in this case, coupling FCR to a water pricing that is more directly linked to water use might generate social tensions because neutralizes the current support to low NI farms. Other problems regard the reconciling of these aspects with the environmental issues of water protection and conservation that may be directly related to farming activity. In fact, unless to cause a drastic economic drop with dramatic repercussions on employment in an area where agriculture represents one of the main income sources, moderately increasing the level of cost recovery allows no relevant reduction of water and nitrogen use. In the light of this, vanishes the assumption at the base of the WFD according to which only paying for the actual cost of water use is possible to increase its efficiency, and thus also safeguard the environment.

All these statements are emphasized under the simulated future climate conditions. This scenario increases the use of water from the RIB, as due to the higher unitary crop water requirements, and the use of nitrogen, due to yield increases for important crops that extend their acreage. The effects of changes in the water tariff regime keep the expected sign, though they prove to be much less intense than in the present climate scenario. In other words, the impact of CC prevails, at least at the lower levels of cost recovery, in influencing the resources use and, afterward, the level of payments and of farming incomes. Even more than under the current climate, in this condition of higher water requirements appreciable reductions in water use are generated only by requiring farmers to pay at the higher levels of recovery, at the cost of drastic reductions in agricultural income in the area. Of course, at those levels of cost recovery, water saving would be achieved only while contemporary maintaining high distributional differences between higher-NI farm types (as some of them, like the RISP, also benefit from CC) and lower-NI types.

7. CONCLUSIONS

The WFD asks water users of all sectors, including the agricultural, to fully cover the costs for water services through a pricing system that establishes a direct link between water use and cost, but meanwhile recommends to pay attention to limit negative social and economic impacts of the recovery. As evidenced discussing the results of this study, all these provisions cannot be met at the same time in the *Oristanese* area. In fact, modifying the current pricing based on hectare-crop fees to adopt the volumetric already determines relevant NI redistributive effects in favour of higher-NI farms types, while not allowing significant reductions in water use and even involving a slight increase in the use of nitrogen. Simultaneously raising the level of cost recovery allows more consistent reductions of surface water usage, however less than proportionally to groundwater and nitrogen, but at the cost of heavy impacts on area NI, unevenly distributed among farm types, and on agricultural employment. Moreover, in this study area the reduction of surface water use does not represent a prior goal, given the non-limiting availability of water from this source, and consequently the choice of introducing the volumetric pricing would not generate any benefit for the collectivity, but on the contrary would be opposed in the light of the high costs for the implementation and management of water-meters, that have not been taken into account in the analysis. Rather, the environmental objectives of the Directive would be better reached through pricing systems that take into exact consideration the components that actually contribute to generate water cost (i.e. the acreage of irrigated land and the average intensity of watering). The consequent more equilibrated reduction of cropping intensity, however, would be achieved at the cost of impacts on labour employment that are even worse.

We are now in a phase of accentuated transition towards the 2030 climatic conditions, and many of the farm types presented in the study could be considered as already experiencing climatic conditions close to that scenario. Therefore, this latter context appears very close to the condition in which would be actually now applied a reform of the irrigation tariff in line with the WFD. The responses of our model indicate that the system would already be sufficiently stressed by the new climatic conditions; therefore, the application of the Directive would have an even more limited effect on the use of water resources, that are pushed to increase by CC. Instead, the impact on NI and its redistribution would be stronger. Also, the dichotomy would remain between fulfilling the environmental objectives of WFD and preventing intense social and economic negative impacts.

So, under both the climate scenarios, but particularly under CC, it appears appropriate to maintain the current pricing system, also considering that the latter, although not directly pricing measured water volumes, still accounts for the water requirements of the different crops, but at the same time allows to avoid the high costs of installation, maintenance and reading of water-meters. With regard to the level of cost recovery, the burden on taxpayers could be relevantly reduced making farmers cover WAC at the modulated agricultural rate, although this would already involve significant income losses for some farm types under CC. In this sense, appears acceptable, from one side, the choice of the Region to cover the extra-energy costs for hydraulic lifting incurred by the RIB as a consequence of local orographic and climatic disadvantages, and, from the other, of the ENAS to modulate the tariffs among the three water demanding sectors according to Article 9, so as to burden at a greater extent industrial users.

Ultimately, the type of analysis performed in this study can help to better specify and support the pricing policies of local water Authorities in the face of the prescriptions of the WFD, making their watershed plans less descriptive. In this way their choices and actions will appear less arbitrary in mitigating social and economic impacts of the application of the Directive.

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