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Which role for public policy?

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**Assessing agriculture-water relationships: a Pan-European
multidimensional modelling approach**

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Abstract

Irrigation water use by agriculture has been identified as one of the major sustainable water management issues in the implementation of the Water Framework Directive (WFD). This paper aims at developing a simulation framework to jointly assess agricultural and water issues. While the strong linkages between water, food, and the environment call for an integrated and multidisciplinary modelling approach, a complete and consistent modelling system to evaluate food-water relationships in Europe was missing so far. The spatial economic simulation model for agriculture CAPRI, which comprises a set of environmental indicators to assess food-environment interrelations within European regions, has been extended to account for food-water links. This modelling framework enables simulating the potential impact of climate change and water availability on agricultural production at the EU regional level, as well as looking at the sustainable use of water, the implementation of water policies or the integration of water issues in the Common Agricultural Policy.

Keywords: agricultural policy, agro-economic modelling, food-water linkages, bioeconomy.

JEL classification: C60, Q11, Q18.

1. INTRODUCTION

Water is vital for agriculture and thus food security. Also, significant impacts on water resources are caused by agricultural activities. More effort is required to analyse the challenges faced by agriculture and the range of policies needed to secure agricultural and water sustainability today and in the future.

In Europe, irrigation water use by agriculture has been identified as one of the major sustainable water management issues in the implementation of the Water Framework Directive (European Commission 2000). Agriculture accounts for an estimated 24% of total water abstraction in Europe, although in parts of southern Europe this figure can reach up to 80% (EEA 2009). Moreover, unlike other sectors like energy production, the majority of the water abstracted for agriculture is consumed (evaporation, transpiration, losses) and is hence not returned to the water bodies (70% according to the EEA).

Since 1985, the area of irrigated land in southern Europe has gone up by 20%, contributing to the fact that the balance between water demand and availability has reached a critical level in many irrigated areas of Europe. But concerns about water scarcity and drought are not longer limited to the Mediterranean. In addition, more and more areas are adversely affected by changes in the hydrological cycle and climate change will almost certainly

exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across Europe and the neighbouring countries (Ciscar 2009, IPCC 2012).

The Commission Communication on the Common Agricultural Policy towards 2020 (European Commission 2010a), while acknowledging agriculture's contribution to a greater resilience to flooding and drought, also recognised negative environmental externalities of farming such as soil depletion, water shortages, pollution, and loss of biodiversity. In order to strengthen a more sustainable water use of agriculture, it proposes to include the Water Framework Directive (WFD) into cross-compliance for the Common Agricultural Policy (CAP) so that a farmer non-compliant with the WFD would lose part of the subsidies paid by the CAP.

In order to analyse agricultural water use and its relation with the CAP, other policies or market developments, water issues need to be covered in tools used for policy impact assessment. This paper therefore develops a joint framework to analyze EU agriculture and water use and discusses first result. It extends a spatial economic simulation model for the agricultural sector, CAPRI (Britz and Witzke 2011), with a module for irrigated agriculture, to complement its existing environmental indicators and agri-environmental modelling capabilities.

This modelling framework enables analyzing the likely impacts of increasing water stress on agricultural production at the EU regional level, as well as looking at the sustainable use of water, the implementation of water policies or the integration of water issues in the Common Agricultural Policy. Preliminary results for a pilot case study in the Andalusia region (Spain) are presented, highlighting the interrelations between water and agricultural developments in Europe.

2. BACKGROUND

The strong linkages between water, food, and the environment call for an integrated and multidisciplinary modelling approach.

Extensive work has been done on integrated assessment of water and food related policies, but most of these studies are site specific and analyse policy impacts at the farm or irrigation district level (Blanco and Iglesias 2005, Bazzani 2005). Some of these studies use a bioeconomic framework, which combines economic and bio-physical modelling. For instance, Moore et al. (2011) develop a modelling system that integrates two biophysical models and a whole-farm economic model to assess the sustainability of alternative farming systems in Australia. However, as these studies remain at the farm or regional level, feedbacks through market prices and water flows across modelling units are lacking.

At the global level, very few agro-economic models deal with water issues. Global coverage entails a lot of simplifying assumptions (regional and sectoral aggregation, limited data, etc.). Yet, there are compelling arguments to choose a global level framework. Markets for agricultural and derived products are globally highly integrated while at the same time trade and domestic support policies affecting agriculture are developed in the context of bi- and multilateral agreements and negotiations. At the same time, key bio-physical processes and concerns are of global or at least supra-national nature such as climate change, hydrological cycles or biodiversity concerns.

The IFPRI's IMPACT model (Rosegrant et al. 2008) is one of the few worldwide models including water as a driver for food supply. IMPACT integrates a global module for agricultural and derived product markets representing 115 socio-economic regional units with a water module dividing the world in 126 river basins. This combined agricultural-food-water modelling framework has been used to analyse water availability, food security, and environmental conservation at basin, country, and global scales (Sulser et al. 2010).

Under a common initiative of IFPRI and IWMI (International Water Management Institute), this modelling framework has been updated and expanded into the WATERSIM model to enable a more disaggregated and comprehensive analysis of the future world food and water situations (De Fraiture and Wichelns 2010).

More recently, the Global Biomass Optimization Model (GLOBIOM), a global partial equilibrium model integrating the agricultural, bio-energy, and forestry sectors, has also integrated water considerations (Sauer et al. 2010). GLOBIOM is a bottom-up model with a detailed representation of the supply side. For each simulation unit, GLOBIOM computes irrigation water consumption, but it does not compute gross water use in terms of actual water withdrawals from surface waters or groundwater. Irrigation water use is constrained through an artificial supply function, representing the relative water scarcity through its increasing marginal cost.

Within Europe, as a rule, the policy support tools currently used for ex ante assessment of EU policies do not take into account water constraints. This is the case with agro-economic models representing the agricultural sector like [AGLINK](#) (OECD 2006), ESIM (Banse et al. 2005), [CAPRI](#) (Britz and Witzke, 2011) and [AGMEMOD](#) (AGMEMOD Partnership 2007).

In a previous attempt to include water indicators in CAPRI, crop-specific water balances were included as passive environmental indicators. Here, we develop a water module, in which irrigation water demand will be treated as endogenous in the model.

3. THE CAPRI WATER MODULE

1. Overview on CAPRI

CAPRI is a partial equilibrium model for the agricultural sector developed for policy impact assessment of the Common Agricultural Policy and trade policies from global to regional scale with a focus on the EU (for a detailed description see Britz and Witzke 2011). It is a deterministic comparative partial static equilibrium model, solved by sequential iteration between supply and market modules (Britz 2008):

- Supply module (EU27+Norway+Western Balkans+Turkey): covering about 280 regions (NUTS 2 level) or even up to ten farm types for each region (in total 1900 farm-regional models, EU27).
- Market module: spatial, global multi-commodity model for agricultural products, about 60 products, 77 countries in 40 trade blocks. Based on the Armington approach (Armington 1969), products are differentiated by origin, enabling to capture bilateral trade flows.

The data bases underlying the model exploit wherever possible well-documented, official and harmonised data sources, especially data from EUROSTAT, FAOSTAT and OECD. Specific modules ensure that the data used in CAPRI are mutually compatible and complete in time and space. They cover about 50 agricultural primary and processed products for the EU, from farm type to global scale including input and output coefficients.

The comparative-static structural nature of CAPRI makes this model mainly suited for counterfactual analysis against an existing baseline or reference scenario. The CAPRI baseline depicts the projected agricultural situation in the simulation year under exogenous assumptions and a status-quo policy setting. The baseline used in this study builds upon the medium-term outlook for EU agricultural markets and income for 2020 (European Commission 2010b) and is based on specific assumptions regarding macroeconomic conditions, the agricultural and trade policy environment, the path of technological change and international market developments.

The extension discussed in this paper relates to the supply module, which consists of independent regional non-linear programming models representing all activities captured by the Economic Accounts for Agriculture (EAA). The supply module currently covers all individual Member States of the EU-27 and also Norway, Turkey and the Western Balkans broken down to about 280 administrative regions, in line with the NUTS2 classification of EUROSTAT.

The programming models are a kind of hybrid approach, as they combine a programming approach - based on a Leontief-technology for variable costs covering a low and high yield variant for the different production activities and constraints such as land, feed and crop nutrient requirements - with a partly econometrically estimated non-linear cost function (Jansson and

Heckelei 2011) which captures the effects of labour and capital on farmers' decisions. The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour (Britz and Witzke 2011).

The regional supply models include a land supply and demand module for arable and grassland, which are treated as imperfect substitutes. Prices are exogenous in the supply module and provided by the market module. Agricultural policy measures are captured in high detail. Some key interactions between agriculture and the environment are also modelled in CAPRI such as agricultural NPK mass flows and GHG emissions from agriculture.

2. *Why an irrigation module for CAPRI?*

The integration of irrigation water in CAPRI instead of in another of the EU wide agricultural market models is motivated by at least two attributes of CAPRI. Firstly, the programming approach of the regional supply models in CAPRI presents advantages to add new activities and constraints compared to other agricultural economic simulation models with EU coverage such as ESIM, AGLINK-COSIMO or AGMEMOD which are multi-commodity models:

- Flexibility to incorporate crop-water relationships (input/output coefficients).
- Flexibility to add new land constraints. Regional constraints on irrigable land could be incorporated but, since irrigated land is currently below irrigable land in all EU regions, these constraints would not have any effect.
- Flexibility to enter irrigation water as a quasi-fixed production factor. In Southern EU regions, irrigation water is a limiting factor for agricultural production.
- Flexibility to estimate environmental indicators at the regional level (irrigation intensity, water use intensity, water stress).

Secondly, compared to other programming approaches, CAPRI covers the whole EU and all agricultural activities and includes market feedback.

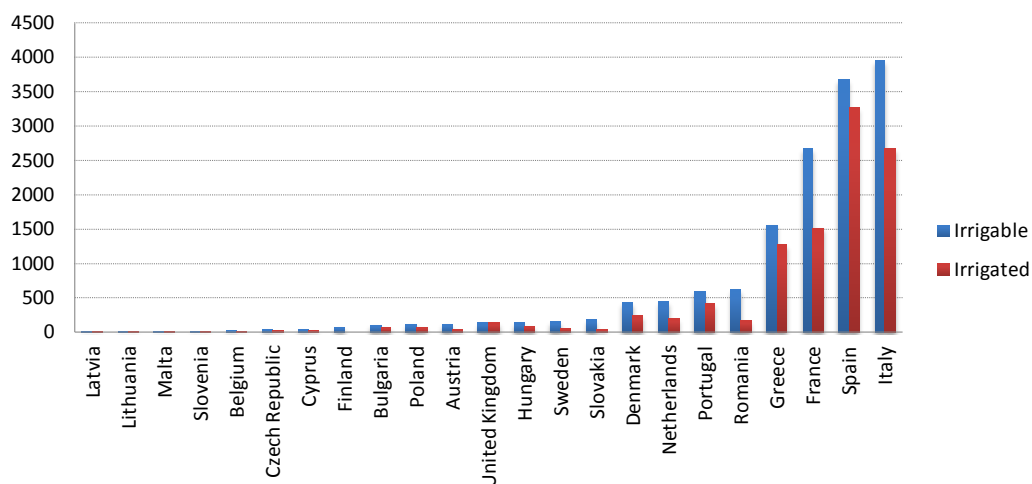
3. *The irrigation sub-module*

Irrigation water use, so far not covered in CAPRI, is the focus of the first phase of construction of the water module, which aims at including water considerations in the supply module of CAPRI (at the NUTS2 level). Data availability to cover the EU at the level of smaller regions is a challenge. Although some data on irrigable and irrigated areas is available at the EU-wide regional level, crop-specific irrigated areas are mostly unavailable and data on irrigation water use is rarely found in official statistics. As a result, EU data sources need to be

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completed with national statistics as well as through a joint estimation procedure for irrigated areas, crop yields and water use.

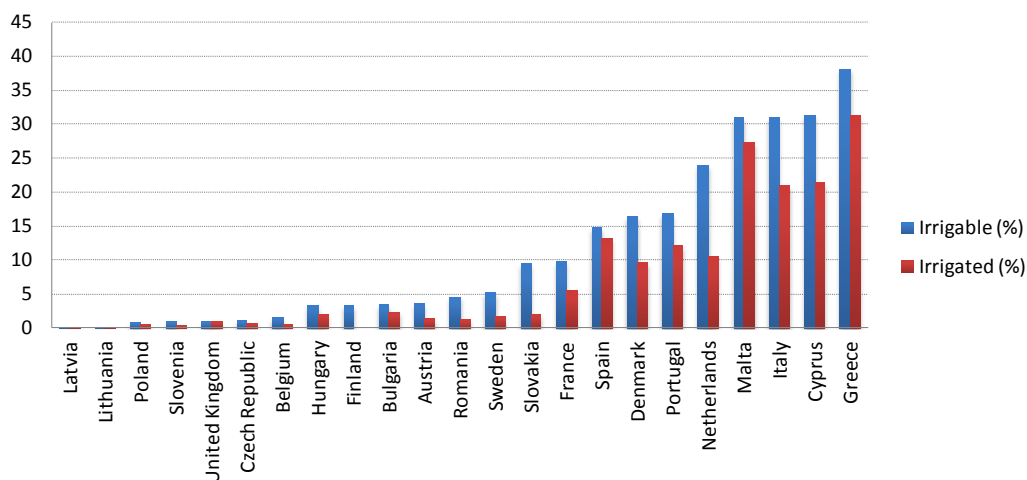
Figure 1. Irrigable and irrigated areas in 2007 (in 1000 ha)



Source: Data from EUROSTAT (no data for Germany, Estonia and Ireland)

Data on area equipped for irrigation (irrigable area) and area irrigated at least once a year (irrigated area) are available in EUROSTAT, as they are regularly collected with the Farm Structure Survey (FSS) and reported by EUROSTAT at MS and NUTS2 levels. The total irrigable area in EU27 was around 15 million hectares in 2007 (16 million hectares in 2003) or 9% of total utilized agricultural area, while the total irrigated area was 10.3 million hectares in 2007 (10.8 million hectares in 2003). As shown in Figure 1, irrigation is mainly relevant in the Mediterranean.

Figure 2. Irrigable and irrigated areas in 2007 (percentage share of UAAR)



Source: Data from EUROSTAT (no data for Germany, Estonia and Ireland)

The share of irrigable area in total UAA is higher than 30% in four Mediterranean countries (Greece, Cyprus, Italy and Malta) and shares at the regional level are even higher in some cases.

To account for irrigation in the supply module of CAPRI, crop activities have been separated into non-irrigable and irrigable. In principle, irrigable activities are those for which an irrigated area has been reported in official statistics in at least one MS. Whereas non-irrigable activities will be handled in the supply module just as before, irrigable activities are split into a rainfed and irrigated variant. If an activity is not irrigated in a particular region, only the rainfed variant exists in the data base and model.

Irrigation water use is included as a crop specific input. As it is not reported in official statistics, estimated values will be used instead. Crop-specific water use is commonly estimated from site specific crop irrigation requirements and climatic data. Various modelling tools have been developed to estimate crop water requirement and the "crop yield response to water". The FAO guidelines to these calculations (Doorembos and Kassam 1979) are widely used and have been recently updated in the AquaCrop model (Raes et al. 2009). Because of its simplicity and robustness, the AquaCrop model could be chosen to estimate crop water requirements, potential yields (non water-limited conditions) and rainfed yields (standard rainfed conditions). An alternative option would be to use data from other biophysical modelling tools (Wriedt et al. 2008). The actual irrigation water use on average per crop (CAWU) will then be estimated for each irrigated region based on theoretical crop water requirements, rainfed and irrigated shares and crop yields.

Regional irrigation water use (*IRWU*) will be computed by summation over all irrigated crops.

$$IRWU_{ri} = \sum_{wact} CAWU_{ri,wact} \times LEVL_{ri,wact}$$

Regarding irrigation costs, EU-wide statistics seem to be lacking. Water is included as a cost item in the European Farm Accounting Data Network (FADN), but this cost component only includes the cost of connection to a water delivery system and the consumption of water. Water application costs as well as irrigation investment costs are not reported separately in FADN. The cost of using irrigation equipment is recorded under "current upkeep of machinery and equipment", "motor fuels and lubricants" and "electricity". As regards capital cost, it is recorded under "investment" and "depreciation".

As production costs given by FADN are not broken down to the level of agricultural activities, CAPRI uses an econometric procedure to allocate farm input costs to particular agricultural activities. In spite of the difficulties to individualize irrigation costs, FADN data

will be used as much as possible to keep consistency with the input allocation model in CAPRI. Nevertheless, as available data on irrigation costs is really limited, additional data from national statistics should ideally be used to fill the gaps in EU-wide statistics.

4. Water indicators

Besides irrigation water use, water demand in the municipal, industrial and livestock sectors will be considered. Simple calculations are applied which are based on water use intensity (e.g. domestic water use per capita) and the related driving force (e.g. population). The main driving forces of water use are population in the municipal sector, industrial production in the industrial sector and herd sizes in the livestock sector.

For each sector, we will distinguish between water withdrawal, total water use and consumptive water use; the ratio of consumptive water use to water withdrawal being the sectoral water use efficiency. Data on sectoral water withdrawal and use is provided by EUROSTAT at the national level (through the OECD-EUROSTAT Joint Questionnaire on Inland Waters). In practice, however, the datasets are incomplete; thus, national statistics will be used whenever possible to fill up data gaps.

Future food-water scenarios may imply changes both in water use intensity and the driving forces of water use and, therefore, may imply changes both in irrigation water demand and irrigation water availability. On the one hand, agricultural water resources are already under stress in many places and rising population and food demand will most likely exacerbate these pressures. On the other hand, agricultural water availability may be jeopardized by increasing water demands in the municipal, industrial and environmental sectors.

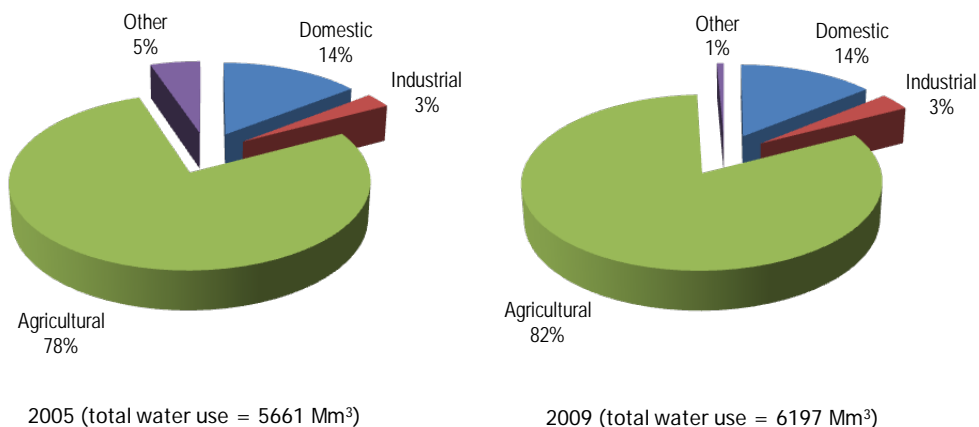
4. PILOT CASE STUDY

The feasibility of the approach has been tested in a case study for the Spanish region of Andalusia, characterized by a high share of irrigation. Differentiation between rainfed and irrigated cultivation has been considered for the main irrigated activities in the region: wheat, sunflower, maize, rice, potato, tomato, other vegetables, olive groves, citrus fruit and other fruits. Ex-post data on rainfed and irrigated areas and yields come from EUROSTAT as well as national statistics. Data on water use and irrigation projections to 2020 are derived from other studies (Junta de Andalusia 2011). Data and model structure for all other NUTS 2 regions remain unchanged.

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As shown in Figure 3, agriculture is the major water user in Andalusia, accounting for about 78% of total water use in 2005 and reaching 82% in 2009.

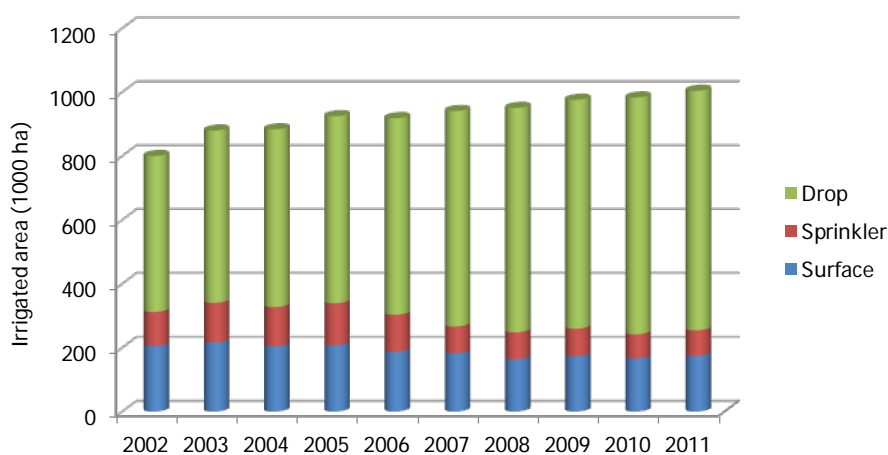
Figure 3. Total water use in Andalusia and sectoral distribution



Source: Own elaboration based on data from the Andalusian Water Agency (www.juntadeandalucia.es).

The increasing share of agricultural water use is mainly due to the gradual expansion of the irrigated area (in particular, to the irrigation of formerly dryland crops such as olive), while the average water application rate is decreasing. The declining trend in water use per hectare can be explained both for the increase in low water intensity crops and for the fast adoption of drop irrigation, replacing surface irrigation (see Figure 4).

Figure 4. Recent evolution of irrigated area in Andalusia



Source: Own elaboration based on data from MAPA 2011.

To illustrate the potentiality of the approach, water policy scenarios, consisting in introducing irrigation water prices, are compared to a baseline situation. The baseline scenario represents the continuation of current policies and the most probable technology development until 2020. It is to a larger extent based on existing medium term outlooks for agricultural markets, but incorporates for Andalusia an estimate about the development of irrigation water use. The counterfactual water pricing scenario differs from the baseline only in the irrigation water price, ranging between 0.2 to 0.4 Euros per cubic meter.

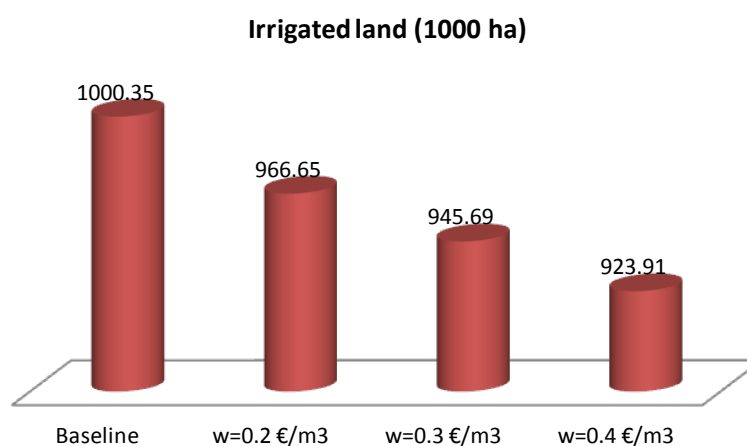
Table 1. Impacts of water prices on Andalusian irrigated areas and water use

	Baseline scenario	Irrigation water price scenario		
		0.2 €/m ³	0.3 €/m ³	0.4 €/m ³
Irrigated area (1000 ha)				
Cereals	87.87	71.66	63.06	54.48
Oilseeds	19.81	14.76	11.92	9.16
Fruits and vegetables	338.33	328.34	321.91	315.05
Olive groves	554.34	551.89	548.80	545.22
Total irrigated land	1000.35	966.65	945.69	923.91
Utilized agricultural area (1000 ha)	5469.25	5469.25	5461.78	5452.23
Irrigation share (%)	18.29	17.67	17.31	16.95
Water use (Mio m ³)	3633.93	3383.79	3245.81	3105.10

Source: Own elaboration

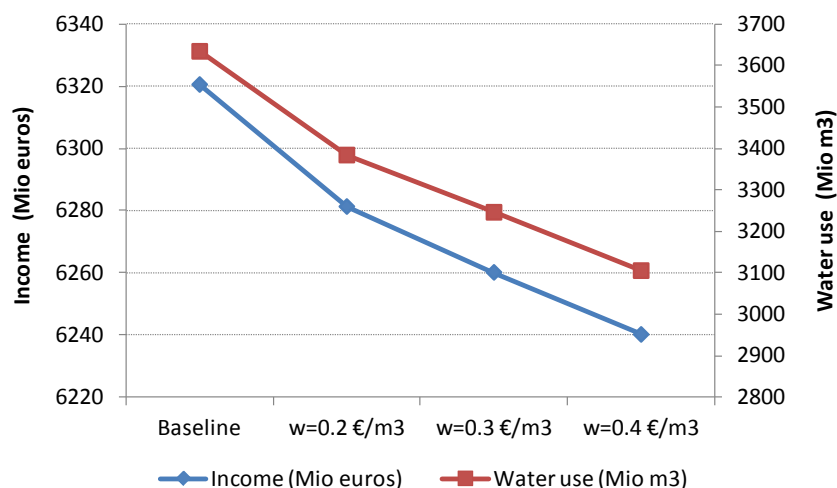
Table 1 displays the impact of irrigation water pricing on irrigated areas and water use. As expected, total irrigated land decreases as the water price increases. Still, irrigated yields increase showing an intensification path on remaining irrigated areas.

Figure 5. Regional irrigated land under alternative water pricing scenarios



Source: Own elaboration

Figure 6. Agricultural income and irrigation water use under alternative water pricing scenarios



Source: Own elaboration

Figures 5 and 6 show the simulated outcomes for irrigated land, regional agricultural income and total irrigation water use. Because of decreasing supply for irrigated crops, producer prices increase as the water price increases. However, in our case study for one European region, that effect is minor, mainly because we simulated a water price increase in only one European region. Consequently, impacts in demand are also not significant. Only for paddy rice the appreciable

These results are very preliminary as the water module is still under development. Nonetheless, they already illustrate the potentiality of the approach to analyse agrifood and water policies in a joint framework. In contrast with most commonly used approaches, feedback mechanism through market prices are taken into account.

5. SUMMARY AND FURTHER STEPS

Incorporating water issues in EU-wide agro-economic models is key to analyse future agricultural policies in a context of climate change and increasing pressure on water resources. The development of the CAPRI water module will enable to provide scientific assessment on agricultural water use within the EU and to analyze agricultural pressures on water resources.

An approach to model irrigation water use has been presented here and tested for a pilot case study in the Andalusia region.

A limiting factor for the development of the irrigation module is the lack of homogeneous and accurate data at EU-wide level for major variables such as irrigation costs, irrigation water use by crop, irrigation efficiency, crop-specific irrigated areas, crop yields under rainfed and irrigated conditions, etc. In some cases, input from other biophysical models could be used as an alternative option.

As a further step, it is foreseen to further develop the CAPRI water module to account for competition between agricultural and non-agricultural water uses in a more detailed way. This will imply building a water use sub-module to simulate water use balances at the regional level.

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