Future scenarios and their implications for irrigated agriculture in the Spanish region of Castilla y León

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Jel classification: C61, D83, Q15, Q18

Abstract

European agriculture is undergoing a deep process of change. The continuous reforms in the Common Agricultural Policy, the volatility of food prices, and the emergence of new driving forces will determine the future of farming activities. Within this context, the main objective of this paper is to analyse the socio-economic and environmental impacts of different future scenarios on irrigated agriculture. For this purpose, simulation models based on Positive Mathematical Programming have been built in order to simulate agricultural producers' behaviour within these scenarios. The results enable us to quantify the influence of individual driving forces, and provide evidence of the utility of this type of prospective analysis in support of public decision-making in agriculture.

Keywords: Prospective analysis, Common Agriculture Policy, Positive Mathematical Programming, Simulation, Sustainability indicators.

Résumé

L'agriculture européenne fait l'objet d'un processus de changement profond. La réforme de la politique agricole commune, la volatilité des prix des denrées alimentaires, et l'émergence de nouveaux éléments moteurs vont déterminer l'avenir des activités agricoles. Dans ce contexte, l'objectif principal de cet article est d'analyser les impacts socio-économiques et environnementaux de différents scénarios sur l'avenir de l'agriculture irriguée. A cette fin, des modèles de simulation basés sur la programmation mathématique positive ont été construits afin de simuler le comportement des producteurs agricoles dans les différents scénarios. Les résultats nous permettent de quantifier l'influence de chaque élément moteur, et de fournir des preuves de l'utilité de ce type d'analyse prospective pour soutenir la prise de décisions publiques dans le domaine agricole.

***Mots-clés:** Analyse prospective, politique agricole commune, programmation mathématique positive, simulation, indicateurs de durabilité.*

1. Introduction

Winds of change are blowing for agriculture. Such a statement could describe any point in the evolution of the sector during recent years, but it is nowadays more obvious than ever. First, the events and processes of adapting to them are taking place ever more rapidly. Examples include the phenomena derived from globalisation (the expansion of international trade in agricultural products), population growth and economic development (rising demand for agricultural products for human and animal consumption), advances in biotechnology (Genetically Modified Organisms or GMOs), the growing shortage of fossil energy sources (leading to increases in the price of agricultural inputs – fuels, fertilisers etc., and growth in demand for energy crops), climate changes (more frequent extreme climatic events), etc. This situation is leading to a new international agricultural scenario. After decades in which agriculture was regarded as a depressed sector with falling prices, the past few years have seen a change in this tendency. This change seems to have taken place in 2007, when the value of raw materials in the world market experienced a drastic increase, reaching their highest historical values. This new high-price situation seems to be structural, since it is caused by factors that are likely to be stable for some time, such as worldwide demand for food products (EC, 2008 and OECD-FAO, 2008). We are thus facing a resurgence of agriculture as a strategic sector at international level.

Secondly, the character of the above changes is significantly different from previous situations. Until a few years ago, the objectives of the change process were productivity improvements (food security) and farm economic efficiency (rises in agricultural incomes). However, the current process is now more complex, as the main driving forces nowadays leading public decision-making regarding the governance of agricultural sector also include aspects, such as the environment, food security and the viability of rural communities, which were virtually ignored until recently. Indeed, recent changes in the sector have become the focus of social and political debate, with the argument that, besides food and raw materials, the agricultural sector also provides other non-commercial goods and services that give it the character of a multifunctional activity (Gómez-Limón and Barreiro, 2007). In the course of the past decade, these considerations have led to a series of policy reforms in developed countries, aimed at adapting the agricultural sector to new social demands. The case of the European Union (EU) is paradigmatic, in that the Common Agricultural Policy (CAP) has been successively reformed in 1992 (MacShar-

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ry Reform), 1999 (Agenda 2000), 2003 (Mid-Term Review), and 2008 (Health Check) with the aim of promoting the development of a more sustainable type of agriculture in economic (competitiveness), social (acceptability) and environmental (eco-compatibility) terms. In this sense, it is also worth mentioning the approval of the Water Framework Directive (WFD) in 2000 in order to further strengthen environmental sustainability regarding water use in the EU. The implementation of WFD involves compulsory water pricing, an economic instrument that is expected to specially impact on economic, social and environmental performance of irrigated agricultural systems (Riesgo and Gómez-Limón, 2006 and Gallego-Ayala and Gómez-Limón, 2008).

This set of circumstances justifies the current interest in studying the future of the agricultural sector, especially in a region like Castilla y León in Spain, where the multifunctional character of agriculture is particularly obvious, but where unprofitability is jeopardizing the survival of the sector and of rural areas (MAPA, 2004). The main objective of this paper is to analyse the economic, social and environmental effects of a range of scenarios in the agricultural sector of Castilla y León. We have therefore performed an empirical study of a particular agricultural system: the Irrigated District of Arévalo-Madrigal (ID-AM) in the province of Avila in central Spain. Thus, although the results of this study can only be directly extrapolated to similar agricultural systems (irrigated areas in Castilla y León with irrigation water from groundwater resources), the study was aimed at testing the utility of this type of prospective analysis as a support tool for agricultural policy decision-making.

The paper is structured as follows: the following section offers a description of the study area analysed. The third section provides a detailed presentation of the methodology adopted for the empirical application and the origin of the information used to feed simulation models. The specific formulation of the models is described in the fourth section. The fifth section synthesises the simulation results. The sixth and final section presents the most relevant conclusions reached.

2. Case study

The Arévalo-Madrigal County is located in the southern part of the Duero Basin in the Province of Avila. This agricultural system is located in the Spanish North Plateau, at an average altitude of 900 m and has a typical continental climate; long, cold and relatively wet winters followed by short, hot and dry summers. Annual rainfall is low, averaging less than 450 mm. Irrigated agriculture is the only alternative to the typical rain-fed cereal monoculture in this area, allowing summer crops to be grown. Some 13662 ha or 9.6% of the total agricultural area of this county are under irrigation (data for 2007 collected in MARM, 2008), integrated in the Irrigated District of Arévalo-Madrigal (ID-AM).

The predominant irrigated crops in the studied district are cereals (barley, wheat and maize) covering 69.3% of the total irrigated area. Industrial crops (sugar-beet and sunflower) are also important, occupying 22.4% of the ID-AM. Other crops include potatoes (2.4%) and alfalfa (1.2%) (MARM, 2008). The remaining crops, such as legumes and vegetables, are of minor importance. The water used by irrigated agriculture is supplied by an important aquifer, Hydrogeological Unit 02.17, also known as *Los Arenales*. The predominant irrigation system is sprinkler technology, which is used to irrigate all crops in the area. The intensive and growing use of groundwater for farming in this area is jeopardizing the sustainability of this water resource, in both quantitative (over-exploitation) and qualitative (nitrate pollution) terms (CHD, 2005).

The ID-AM comprises 1133 farms, for an average irrigated farm size of 12.1 ha (INE, 2001). Nonetheless the heterogeneity of farms in the study area is considerable. With the aim of characterizing this diversity, we developed a farm typology via a cluster analysis based on the farmers' crop-mix as a classificatory variable (see sections 3.3 and 3.5). This defined three homogeneous groups, with their respective farm-types. Table 1 shows the main features of these farm-types.

Table 1 – *General features for the farm-types.*

	Group 1 (G1) *Large cereal growers*	**Group 2 (G2)** *Cereals sugar-beet growers*	**Group 3 (G3)** *Small sugar-beet growers*	**Whole sample**
Percentage of farmers	31.2%	50.0%	18.8%	100%
Percentage of total area	68.4%	29.5%	2.1%	100%
Farm size (ha)*	115.8	31.3	6.0	52.0
Percentage of irrigated land in own property	93.0%	68.6%	66.7%	85.2%
Age (years)	49.5	54.0	50.2	51.8
Time devoted to agricultural activity	90.0%	91.3%	100.0%	92.5%
Percentage of farmers with secondary or university study level*	70.0%	12.5%	0.0%	28.1%
Main crops*	W. cereals (67%), sugar-beet (13%), maize (9%)	W. cereals (64%), sugar-beet (21%)	Sugar-beet (93%)	W. cereals (65%), sugar-beet (17%)

* Variables with statistically significant differences among clusters (application of ANOVA test for quantitative variables and chi-squared for categorical variables).

Our interest in the case study area selected for this study is based on this being an agricultural system that is highly dependent on CAP subsidies, where conflicts between private interests (farmers' private profitability) and the authorities (rural development and eco-compatibility, and quantitative and qualitative pressures on the aquifer) are clearly visible.

3. Methodology

3.1. Scenarios analysed

The methodological approach adopted in order to build the scenarios for the agricultural sector of Castilla y León to 2020 was the *prospective technique*, as systematised by Godet (1987, 2001). Briefly, this method is based on the three main stages listed below:

- *Structural analysis*. The structural analysis is a systematic method that identifies the interrelationships among the variables that characterise a system. For this purpose the following activities have been developed: a) identification of variables, b) construction of the structural analysis matrix, and c) search for the key variables. All these steps were carried out with the assistance of multidisciplinary panel of external experts composed by academic researchers and technical experts from the regional administration. This enabled us to identify 12 key driving variables that will determine the future of agriculture in Castilla y León. In any case, these key variables were grouped into three vectors of change that were regarded as main driving forces: a) agricultural production, b) demand for agricultural products, and c) institutional framework.
- *Morphological analysis: partial and global scenarios building*. Once the most relevant drivers were selected, the next step was the construction of the "partial scenarios". To this end, we established several future alternatives for each of the drivers selected in the previous stage for the 2020 horizon. Such possible alternatives make up a partial scenario derived from the corresponding driver. Each partial scenario has been formalised through a relatively detailed narrative description of its essential features, the so-called "story-lines" in the terminology of the prospective. The scenarios proposal was submitted to public discussion with the external experts from the previous phase (the structural analysis) and with a representative group of economic and social actors related to the agricultural sector in the region (producer organizations, environmental groups, governments and other groups). The outcomes of these deliberations formed the basis of the review of the initial scenarios. In this way, they defined the final partial scenarios to the three drivers considered (see Table 2). The scenario-building process ended with the development of the "global scenarios" derived from all the feasible and logical combinations of the different partial scenarios. Finally, we remained with only four global scenarios that could be regarded as truly representative of the future development of the agricultural sector in the region of Castilla y León (see also Table 2).

Table 2 – *Drivers. Partial and global scenarios.*

DRIVERS	**PARTIAL SCENARIOS**			
Agricultural production	Abandonment for leisure purposes (A1)	Productive commercial agriculture (A2)	Multifunctional family agriculture (A3)	
Demand for agricultural products	Business-as-usual (B1)	Global consumerism (B2)	Responsible consumption (B3)	
Institutional framework	Business-as-usual (C1)	Liberalization (C2)	Regionalization (C3)	Strengthening (C4)
	GLOBAL SCENARIOS			
	Business-as-usual (A1+B1+C1)	**Triumph of the market (A2+B2+C2)**	**Regional sustainability (A3+B3+C3)**	**European sustainability (A3+B3+C4)**

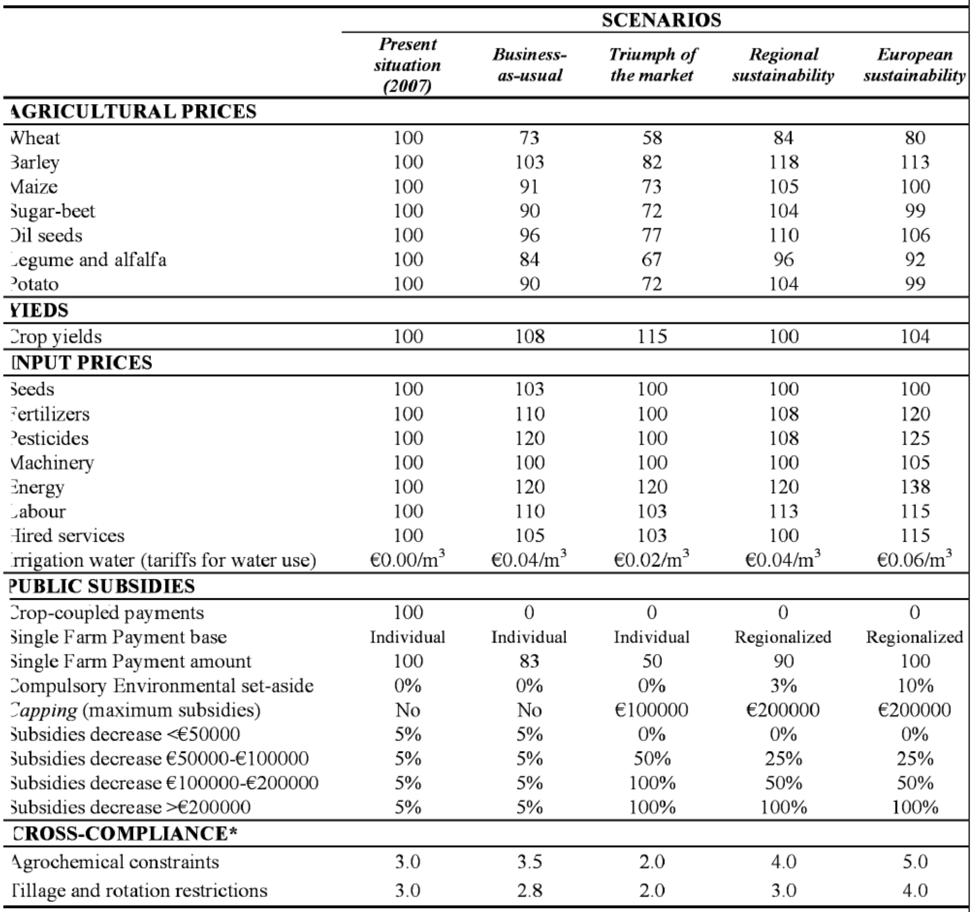
* Source: Gómez-Limón et al. (2009).

- *Quantitative characterization of the global scenarios*. The global scenarios generated from the morphological analysis were substantiated in short narratives (story-lines) that describe their main characteristics. However, these qualitative results were not enough. The operability of the scenarios for their subsequent modelling requires the complementation of these narratives with the quantification of certain key variables or parameters. For this purpose, we applied the Delphi method (Adler and Ziglio, 1996) as a useful technique to discuss and to reach the necessary consensus about the feasible values of the different variables considered in each future scenario (see Table 3 for the results finally achieved). Once again the same panel of experts mentioned above supported the authors for this task.

The basic characteristics of the four global scenarios built in this way can be summarised as follows:

- *"Business-as-usual"*. This scenario assumes that the trends observed in regional agriculture over the past few years will continue. From an institutional point of view, development will take place within the framework of a CAP with tighter budgetary restrictions. Direct payments to production, which will be smaller than they are at present, assume the total decoupling of direct subsidies, and are received through an individualised Single Farm Payment (SFP), as at present. However, these subsidies will be conditional on stricter environmental requirements. On the other hand, with regards to agricultural production it is assumed that new crop techniques will be adopted in order to reduce costs (for example, a switch from conventional tillage to minimum tillage or direct sowing), as a strategy for dealing with increases in the prices of agricultural commodities. A widespread use of GMO crops is also expected.

Table 3 – *Quantitative characterization of global scenarios.*



	SCENARIOS				
	Present situation (2007)	*Business-as-usual*	*Triumph of the market*	*Regional sustainability*	*European sustainability*
GRICULTURAL PRICES					
heat	100	73	58	84	80
arley	100	103	82	118	113
aize	100	91	73	105	100
ugar-beet	100	90	72	104	99
il seeds	100	96	77	110	106
egume and alfalfa	100	84	67	96	92
otato	100	90	72	104	99
IEDS					
rop yields	100	108	115	100	104
NPUT PRICES					
eeds	100	103	100	100	100
ertilizers	100	110	100	108	120
esticides	100	120	100	108	125
achinery	100	100	100	100	105
nergy	100	120	120	120	138
abour	100	110	103	113	115
ired services	100	105	103	100	115
rrigation water (tariffs for water use)	€0.00/m^3	€0.04/m^3	€0.02/m^3	€0.04/m^3	€0.06/m^3
UBLIC SUBSIDIES					
rop-coupled payments	100	0	0	0	0
ingle Farm Payment base	Individual	Individual	Individual	Regionalized	Regionalized
ingle Farm Payment amount	100	83	50	90	100
ompulsory Environmental set-aside	0%	0%	0%	3%	10%
apping (maximum subsidies)	No	No	€100000	€200000	€200000
ubsidies decrease <€50000	5%	5%	0%	0%	0%
ubsidies decrease €50000-€100000	5%	5%	50%	25%	25%
ubsidies decrease €100000-€200000	5%	5%	100%	50%	50%
ubsidies decrease >€200000	5%	5%	100%	100%	100%
ROSS-COMPLIANCE*					
grochemical constraints	3.0	3.5	2.0	4.0	5.0
illage and rotation restrictions	3.0	2.8	2.0	3.0	4.0

Source: Gómez-Limón et al. (2009).
Measured on a Likert scale (from 1 to 5), where "3"·means the current cross-compliance, "1" means a drastic reduction in cross-compliance requirements and "5" means a major increase in cross-compliance requirements.

In this scenario it is also assumed that the WFD is implemented by pricing irrigation water at €0.04/m^3. This would be an attempt to apply the cost recovery principle considering only the financial costs (this price would not be capable of recovering environmental costs, i.e. damages that irrigation water use causes to the environment).

- *"Triumph of the market"*. This scenario is the result of a mercantilist concept of future society. The first remarkable fact is therefore the broad agreement in the World Trade Organization (WTO) to the liberalization of world trade in agricultural products. In line with this, a new political framework will be established, which will be characterised by the CAP budget minimised (considerable decrease in support for farmers' profits) and the removal of protectionist tariff barriers. The payments received by producers, which will be much lower than the current levels, assume the total decoupling of direct subsidies and will be received via SFP. In contrast to the previous scenario, the environmental requirements linked to production will be more flexible, in order to improve international competitiveness. Furthermore, in this new context, a process of reconversion to agricultural production will take place, which will include new cost-saving technologies and the widespread adoption of GMOs. Within this scenario it is considered that compulsory irrigation water pricing fixed by the WFD is implemented through a "subsidised" price of €0.02/m^3. This option reflects a low interest in putting into practice environmental taxation.
- *"Regional sustainability"*. This scenario describes a future that takes into account the environmental and social aspects of agriculture. As a result, the Common Market Organization (CMO) negotiations will not reach agreement, a situation that will lead to unregulated international trade in agricultural products. Developed countries will react to this situation with commercial protectionism (increasing tariff barriers for agricultural products) which will enable them to increase their domestic prices. In institutional terms, this scenario will be characterised by a CAP with a lower budget, within which each EU member state will determine its own form of agriculture governance (partial renationalization). Furthermore, a total decoupling of subsidies will be introduced throughout the EU, to be distributed among producers through regional payments. More restrictive cross-compliance and modulation measures will therefore be implemented, and more support will be provided for agri-environmental programs, encouraging the adoption of new environmentally friendly technologies. As in the *Business-as-usual* scenario, in this case the implementation of WFD is assumed to be done by an irrigation water tariff equal to €0.04/m^3 (only financial costs are considered to apply cost recovery principle).
- *"European sustainability"*. This scenario is a variation of the previous one, where the environmental and social issues related to agriculture are also important, but are dealt with in a common EU perspective, in which the CAP is sustained as an essentially European policy. At institutional level we can foresee an increase in the community's agricultural policy budget, which will be operationally simplified through regionalised payments that will be subject to strict cross-compliance and modulation criteria. Nevertheless, this new CAP will prioritise a policy of rural development as opposed to the traditional agricultural policy of supporting agricultural incomes. This scenario will reinforce the multifunctional character of agriculture, while at the same time developing com-

plementary activities to agriculture in rural areas. This emphasis in environmental concerns justifies the consideration of a water tariff of €0.06/m^3. This price would be a tough application of the full-cost recovery principle in the basin, including a provision for environmental costs.

For more detailed definitions of the global scenarios presented above, interested readers can consult the work by Gómez-Limón et al. (2009).

The empirical study performed in this work simulated the previous four scenarios with the aim of evaluating their impacts on the agricultural system analysed. However, regarding the alternative future scenarios, we decided to analyse an additional one: "*CAP-reformed"*. This scenario refers to the agricultural policy that came into effect in Spain in 2006, after the application of the CAP Mid-Term Review and the introduction of the CMO sugar reform. It thus takes into consideration the CAP effect of the partial decoupling of direct subsidies, i.e. the maintenance of direct coupled payments (linked to crop area) equal to 25% of the support previously received (€15.75 t^{-1} for cereals, oilseed and protein crops) and the introduction of the SFP scheme through which the remaining 75% support is provided. This scenario also includes the restructuring of the sugar sector promoted by the new sugar CMO, which is characterised by: a) a decrease in the price of sugar beet from €48.00 t^{-1} to €40.00 t^{-1}, b) the integration of sugar-beet into the SFP, which now also includes an annual €11.00 t^{-1} during the biennium 2004-2005, and c) the compulsory abandonment of 50% of production, with farmers being compensated with €40.00 t^{-1} delivered on average during 2004-2008. Finally, for this scenario it has been assumed that the applicable prices for agricultural products and inputs are those that existed in 2007, prior to agricultural markets shock occurred in 2008 and 2009.

Finally, in order to make the results topically relevant, all of them have been compared with the reference scenario *"CAP-2005"*. This scenario corresponds to the previous political framework, derived from "Agenda 2000", and is characterised by public support for the agricultural sector through direct payments per unit area based on theoretical yields at county level (€63.00 t^{-1} of theoretical county yields for cereals and oilseeds; protein crops, payments increased to a limit of €72.50 t^{-1}). Product and commodity prices are those of 2005. This scenario is treated as the baseline scenario to be compared with the other scenarios.

With regard to the global scenarios we have described, it should be pointed out that these are stereotyped images of the future of agriculture in Castilla y León. In any case, we believe these scenarios are of practical interest to the extent that they enable to reflect in some depth on the design and implementation of policies that affect the agricultural sector (i.e. CAP reforms, WFD implementation, etc.)[1]. A better understanding of what is likely to happen should allow us making better judgments about the pros and cons of each of these scenarios in our near future, being a useful information to support a more suitable public decision-making in the present. Thus, the final objective of this work is analysing the economic, social and environmental impact of different future scenarios, just in order to establish political lines capable of channelling the agricultural system studied into a desirable future.

3.2. The simulation technique: Positive Mathematical Programming

Positive mathematical programming (PMP), which was developed by Howitt (1995), is a mathematical modelling technique based on a calibration system, which establishes non-linear cost functions that allows the same cop-mix distribution as the one observed in the real world to be reproduced, by using the information contained in the dual values of the decision variables (crops). PMP assumes that the productive activity observed in a given farm or set of farms is a result of the farmer's profit maximization behaviour. The differences in farmers' observed behaviour are thus due to the different production costs faced by them as individuals.

The PMP calibration described by Howitt (1995), also known as the "standard PMP approach", is based on three steps. The first step consists of building a Linear Programming (LP) model in order to obtain the dual-value variables for each of the activities (crops) considered. The next uses the dual-value variables to calibrate the cost function of the individual crops. Finally, the cost function parameters are used to define a new objective function for the PMP model. The LP model developed in the first step is thus transformed into a non-linear programming model that will reproduce the base year crop distribution, and that can therefore be used to simulate future or hypothetical scenarios that would lead to new productive behaviour. For this reason, the PMP has been widely accepted by economists as a way of analysing the *ex-ante* impacts of potential scenarios and policy instruments that affect the agricultural sector.

However, this primitive focus has been severely criticised, and certain important shortcomings of the technique have been identified (see Heckelei and Britz, 2005 and Henry de Frahan et al., 2007). This led to further development of the PMP, with the aim of minimizing the drawbacks of the original method. In the context of PMP development, Röhm and Dabbert (2003) proposed an extension which permitted a higher degree of substitution between similar crops (called "variant activities"), rather than between other less closely related crops (activities). These variant activities are taken into account in order to obtain more realistic results. Thus, the concept of variant activities can be applied to the same crop that is grown under different techniques, as well as to crops from the same family that are equally well adapted to local conditions and are equally susceptible to the same pests (Röhm and Dabbert, 2003).

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[1] Futurists often remind that the purpose of thinking about the future is not to predict what will happen but rather to consider alternatives.

The mathematical formulation of this extension of the PMP can be summarised as follows. Bearing the various activities (*i*) and possible variants (*j*) in mind, the initial model is formulated as follows[2]:

$$Max\ TGM = \sum_i \sum_j \left(p_{i,j} \cdot y_{i,j} - c_{i,j} + s_{i,j}\right) x_{i,j} \tag{1a}$$

Subject to:

$$\sum_i \sum_j \left(x_{i,j}\right) \leq \sum_i \sum_j \left(x^0_{i,j}\right) \tag{1b}$$

$$\sum_j \left(x_{i,j}\right) \leq \sum_j \left(x^0_{i,j}\right)\left(1+\varepsilon_1\right) \qquad \forall i \tag{1c}$$

$$x_{i,j} \leq x^0_{i,j}\left(1+\varepsilon_2\right) \qquad \forall i, j \tag{1d}$$

$$\varepsilon_2 > \varepsilon_1 \tag{1e}$$

$$x_{i,j} \geq 0 \tag{1f}$$

Equation (1a) represents the objective function of the LP model, where TGM is the total gross margin (assuming profit maximization)[3]. The TGM is calculated as the sum of the gross margins resulting from each activity. For this reason, the objective function is logically a function of the area allocated to each crop, $x_{i,j}$ (hectares devoted to crop *i*, with variant *j*). These $x_{i,j}$ are treated as the decision variables of the model. In order to calculate the TGM we also need the following technical coefficient data: price ($p_{i,j}$), yield ($y_{i,j}$), variable cost ($c_{i,j}$) and CAP direct subsidies, coupled to the production per unit area ($s_{i,j}$) for each crop that can be regarded as alternatives.

The above model includes a set of constraints that can be interpreted as follows. Equation (1b) limits the land available for irrigated crops, where $x^0_{i,j}$ represents the crop-mix observed in the base year. Equation (1c) represents the constraints on total activities, ε_1 being a small positive number. Finally, equation (1d) represents the constraints on the variant activities, with ε_2 being another small positive number that must satisfy equation (1e).

The addition of equations (1c) and (1d) forces an optimal solution in the LP model that reproduces the activities observed in the base year ($x^0_{i,j}$). As a result of the introduction of the final two constraints, the model solution generates the dual values for the various activities. Equation (1c) produces the dual values of activities λ_i and equation (1d) indicates the dual values of the variant activity $\lambda_{i,j}$.

Once the dual values have been obtained, they are used to calibrate the cost function of the individual activities. These parameters are also used to define the new objective function for the PMP model. Eq. [2] presents the objective function of the PMP extended version of Röhm and Dabbert (2003) including these non-linear cost functions:

$$Max\ TGM = \sum_i \sum_j \left\{ x_{i,j} \left[y_{i,j} p_{i,j} - c_{i,j} \left(\alpha_{i,j} + \beta_{i,j} x_{i,j} + \gamma_{i,j} \sum_j x_{i,j} \right) + s_{i,j} \right] \right\} \tag{2}$$

where $\alpha_{i,j}$ (the axis intercepted coefficient), $\beta_{i,j}$ (the slope coefficient of variant activity level) and $\gamma_{i,j}$ (the slope coefficient of total crop activity) denotes the cost function parameters that takes the following mathematical expressions:

$$\alpha_{i,j} = 1 - \frac{\lambda_i + \lambda_{i,j}}{c_{i,j}}; \qquad \beta_{i,j} = \frac{\lambda_{i,j}}{c_{i,j} x^0_{i,j}}; \qquad \gamma_{i,j} = \frac{\lambda_i}{c_{i,j} \sum_j x^0_{i,j}} \tag{3}$$

This extended version of PMP has also been criticised, particularly because of the implicit subjectivity in the definition of the groups of variant activities, given that this grouping might influence the response of the models (Blanco et al., 2008). However, the extended version of the PMP method has been widely adopted, and has been used in several recent studies; e.g. Cortignani and Severini (2009), Gallego-Ayala and Gómez-Limón (2009) and Henseler et al. (2009).

3.3. Decision-making heterogeneity and cluster analysis

Modelling farming activity at agricultural system level (or at any other level that deals with a set of individual farms) involves problems of aggregation bias (Hazell and Norton, 1986). This aggregation bias can only be avoided if the farms included in the models fulfil strict homogeneity criteria (Day, 1963): technological homogeneity, pecuniary proportionality and institutional proportionality.

The irrigated district under consideration as case study is located in a single agricultural county and uses a single source of water. Hence, bearing in mind soil-quality homogeneity, and technological, institutional and market characteristics, we can regard the case study area as an analytical unit that fulfils the above-mentioned homogeneity criteria. Thus, it might seem reasonable to assume similar behaviour on the part of all farmers in the study area, which would mean that the operation of the policy instruments being considered could be analysed through a single simulation model with relatively small problems of aggregation bias. However, this assumption must be rejected. Indeed the experience accumulated in this field shows that the real behaviour of individual farmers belonging to the same agricultural system differs widely, mainly due to the heterogeneity of crop costs (non-fulfilment of pecuniary proportionality). For this reason, in order to avoid the aggregation bias in simulation, it is necessary to classify farmers into homogeneous groups with regard to their crop-mixes, i.e. groups that include farmers with similar cost functions.

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[2] For detailed information about the mathematical development of this PMP approach, see Röhm and Dabbert (2003).

[3] Economically gross margin is defined as the difference between incomes and the variable costs. This concept is usually taken as a proxy of profit for modelling purpose, because the calculation of the later concept is much more data demanding (profit is the difference between incomes and total cost, both variable and fixed ones).

In order to develop a typology of producers, we carried out a survey of the farmers in the ID-AM in order to gather information about their productive structure. This information, and more specifically the variables regarding the crop-mix (areas of crops expressed as percentages), was used to apply cluster analysis. This multi-variant technique was implemented by taking the Euclidean squared distance as a measure among actual crop-mixes and the Ward or minimum variance method as the aggregation criterion. This produced the three groups of irrigators mentioned in section 2. The corresponding farm-types, which are representative of the whole group of farms in the study area, were treated as the unit of analysis for building the simulation models. An individual model was built for each homogeneous group of farmers in order to simulate the proposed scenarios independently.

3.4. Impact indicators: economic, social and environmental indicators

Irrigated agriculture has economic, social and environmental implications (Gómez-Limón et al., 2007). The empirical application to be performed therefore needs to quantify the impacts of the scenarios proposed, through a range of indicators that covers them.

a) Economic indicators:

- *Total gross margin (TGM)*. This is the difference between income (sales and subsidies, both coupled and decoupled and included in the SFP) and total variable costs measured in €·ha^{-1}. The gross margin can be regarded as a valid estimator of the private profitability in the agricultural activity.

- *Public subsidies to agriculture (PUBSUB)*. This indicator attempts to measure the budgetary input provided by the authorities through subsidies in the various scenarios. The measurement unit of this indicator is €·ha^{-1}.

b) Social indicators:

- *Farm employment (EMPL)*. This indicator, measured in Labour·ha^{-}1, allows the contribution of the agricultural sector to rural development and territory balance (population settlement, income distribution, etc.) to be quantified.

- *Seasonal labour employment (SEASON)*. Farm labour requirements can be fulfilled by permanent workers (either the own farmer or external workers), usually with residence in the surrounding areas, or temporary ones, mainly employed for seasonal activities (e.g. harvesting or any other activity demanding labour). These temporary workers are sometimes residents, but also workers from outside the county are employed, being the latter much more important in terms of man-days of labour. In this sense it is assumed that labour seasonality does not contribute to the maintaining of rural population. In order to be operative with this idea, this indicator quantifies the demand for farm labour at peak periods during the year, measured in percentage of total labour required, which may be regarded as a suitable estimator to measure farming's contribution to fixing population to rural areas.

c) Environmental indicators:

- *Water use (WATER)*. The amount of water used for irrigation expressed in m^{3}·ha^{-1} permits the quantitative pressure exerted by agriculture on the aquifer from which water is drawn to be measured.

- *Nitrate balance (NBAL)*. This balance is the difference between the nitrogen content of inputs and outputs. The difference measured in kg N·ha^{-1} represents the amount of nitrogen leached into the environment, which in turn is an indicator of the environmental impact of irrigated agriculture on groundwater quality.

- *Soil cover (SOILCOV)*. This indicator represents the percentage of days per year during which vegetation covers the soil. It can thus be regarded as an estimator of soil erosion risk. The measurement unit of this indicator is %.

- *Energy balance (EBAL)*. This balance is calculated via an input-output approach as the difference between the energy contained in the harvest, and the energy contained in the inputs used in production plus the energy needed to perform agricultural activities. This indicator is expressed in kcal·ha^{-1} and tries to quantify the contribution of irrigated agriculture as an agent of CO_2 capture (reduction of greenhouse gases) and thus as an element that mitigates climate change.

- *Pesticide risk (PESTRISK)*. This indicator quantifies the living organisms potentially killed by action of pesticides. This indicator provides information about the toxicity released into the environment by irrigated agriculture. The measurement unit of this indicator is kg·ha^{-1}.

The value of each indicator was calculated for each scenario and farm-type, applying technical coefficients to the model results (crop-mix). The value of these technical coefficients was obtained from primary data sources, excepted for the *NBAL*, *EBAL* and *PESTRISK* indicators, for which Dominguez-Vivanco (1997), Volpi (1992) and Gómez de Barreda et al. (1998) respectively were consulted. For further details about the methodology employed to calculate the indicators, see OECD (2001) and Bazzani et al. (2004).

3.5. Data sources

Simulation input data were gathered from primary and secondary sources. Secondary data, in particular regarding prices and yields, were extracted from the *Anuarios Agroalimentarios de Castilla y León* (CAG, various years). Primary data were obtained from two surveys. The first focused on agricultural technicians working in the ID-AM (agricultural extension service experts, farmers' organization advisors, university research staff), and was aimed at collecting information about production techniques and input prices. Seven experts were consulted. The second survey focused on irrigators working in the ID-AM, and aimed to collect information about crop-mix, farm structural variables and the socio-demographic characteristics of farmers. A total of 62 farmers were interviewed.

The data collected from primary and secondary sources described the *CAP-2005* scenario situation. For this reason the data were only directly used for modelling that scenario. Bearing in mind that several data items concern parameters of change in the remaining scenarios (i.e. agricultural prices of products and inputs, CAP subsidies, etc,), this data had to be modified for each case, in accordance with the variations set out in Table 3.

4. Modelling

In order to construct the simulation models for each farm-type, it was necessary to take into account the area given over to each crop, as decision variables ($x_{i,j}$). Taking the PMP extension followed into account, the activities chosen for modelling were thus defined as follows: irrigated winter cereals (x_1), with the two variants of irrigated wheat ($x_{1,1}$) and irrigated barley ($x_{1,2}$), rain-fed wheat (x_2), rain-fed barley (x_3), maize (x_4), irrigated sunflower (x_5), rain-fed sunflower (x_6), sugar-beet (x_7), potato (x_8), irrigated alfalfa (x_9), rain-fed alfalfa (x_{10}) and set-aside (x_{11}). Rain-fed crops were included as alternatives, in order to increase the flexibility of the model, allowing farmers the option of ceasing irrigation and sowing these crops in rain-fed areas, as happens in the real world.

4.1. Modelling baseline scenario "CAP-2005"

The objective function for *CAP-2005* corresponds to equation (2). However, this function is subject to the following constraints:

$$\textit{Surface constraint:} \qquad \sum_i \sum_j x_{i,j} \le SUR \tag{4a}$$

$$\textit{Alfalfa rotation constraint:} \qquad x_9 + x_{10} \le 55\% \cdot SUR \tag{4b}$$

$$\textit{Sugar-beet CAP constraint:} \qquad x_7 \le \frac{\textit{sugar-beet quota}}{\textit{sugar-beet yield}} \tag{4c}$$

$$\textit{Alfalfa market constraint:} \qquad x_9 + x_{10} \le \textit{historic maximum value} \tag{4d}$$

$$\textit{Potato market constraint:} \qquad x_8 \le \textit{historic maximum value} \tag{4e}$$

Equation [4a] limits the crop area to the total surface currently available in the farm (*SUR*). The constraint [4b] was included so that the optimum crop plans resulting from the model would respect the agronomic restrictions of alfalfa growing[4]. Expression [4c] was incorporated in order to allow the appropriate simulation of sugar-beet, due to CAP quota for this crop, that limits the maximum hectarage to be sown in each farm. Finally, expressions [4d and 4e] represent the market constraints relating to potato and alfalfa. These constraints are included due to the crop rigid demand. Therefore, the demand for alfalfa and potato is unlikely to exceed the maximum production of the last 10 years[5]. The set of constraints (4a) and (4b), (4d) and (4e), which are kept constant for the remaining models, is represented hereafter as (base model constraints).

This is the model from which the calibration parameters λ_i and $\lambda_{i,j}$ were estimated, allowing for the simulation of the remaining scenarios, as $A\vec{X} \le \vec{B}$ detailed in the following sections.

4.2. Modelling scenario "CAP-reformed"

On the basis of the calibration made using the PMP extended version, we constructed the model for *CAP-reformed* scenario. Equation (5a) describes the objective function that includes the individual single farm payment (SFP_{ind}) scheme, as a consequence of the reformed CAP, calculated on the basis of subsidies historically received by producers, and the compensation for the compulsory abandonment of sugar-beet (*SUBAB*)[6]. This model is as follows:

$$Max\ TGM = \sum_i \sum_j \left\{ x_{i,j} \left[y_{i,j} p_{i,j} - c_{i,j} \left(\alpha_{i,j} + \beta_{i,j} x_{i,j} + \gamma_{i,j} \sum_j x_{i,j} \right) + s_{i,j} \right] \right\} + SFP_{ind} + SUBAB \tag{5a}$$

Subject to:

$$\textit{Base model constraints:} \qquad A\vec{X} \le \vec{B} \tag{5b}$$

$$\textit{Sugar-beet abandonment constraint:} \qquad x_7 \le 50\% \frac{\textit{sugar-beet quota}}{\textit{sugar-beet yield}} \tag{5c}$$

This model differs from the previous one insofar as it includes the compulsory abandonment of 50% of sugar-beet production by all farmers, as reflected in constraint (5c). Moreover, the technical coefficients regarding prices ($p_{i,j}$), cost ($c_{i,j}$) and direct subsidies ($s_{i,j}$) corresponding to the year 2007 were used in order to ensure that this scenario was modelled correctly.

4.3. Modelling scenario "Business-as-usual"

The suggested simulation model of the *Business-as-usual* scenario is as follows:

The difference between models (5) and (6) is the elimination of the compensation for the compulsory abandon-

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[4] As it is well known, alfalfa is a multiannual crop, sown in the case study area in a four years period (*n*=4). Once this period expires and the plantation is removed, alfalfa is not sowed again during 3 years in the same plot (*m*=3) due to the presence of some phytotoxins for this crop in the ground. However, any other crop is possible. Hence, an agronomic constraint regarding the rotation of this crop is needed:

$$x_{alfalfa} \le \frac{m}{m+n} \times SUR = \frac{4}{4+3} \times SUR \approx 0.55 \times SUR$$

[5] In the case of alfalfa, this constraint is included due to the crop rigid demand derived from the (almost) fixed requirements for feeding regional flocks of livestock (their size is fairly constant caused by the CAP quotas). For potatoes the case is similar, due to a human consumption constraint because of population stability.

[6] Taking into account that this additional payment of € 40.00 per non-produced tonne of sugar-beet is received only once. We therefore annualized it at an interest rate of 5%, i.e. € 0.80 t year^{-1}. Hence, *SUBAB* equals 0.80↔50%↔sugar-beet quota.

$$Max\ TGM = \sum_i \sum_j \left\{ x_{i,j} \left[y_{i,j} p_{i,j} - c_{i,j} \left(\alpha_{i,j} + \beta_{i,j} x_{i,j} + \gamma_{i,j} \sum_j x_{i,j} \right) \right] \right\} + SFP_{ind} \qquad (6a)$$

Subject to:

Base model constraints: $A\vec{X} \leq \vec{B}$ (6b)

Sugar-beet abandonment constraint: $x_7 \leq 50\% \dfrac{\text{sugar-beet quota}}{\text{sugar-beet yield}}$ (6c)

ment of the sugar-beet (*SUBAB*) in the latter model. This is a logical variation, since the current subsidies do not influence decision-making in a long-term simulation (horizon 2020). Furthermore, the alfalfa and potato market constraints (equations [4d] and [4e] included base model constraints $A\vec{X} \leq \vec{B}$) in order to simulate this and the next future scenarios with a wider degree of freedom. More concretely, both constraints have been modified for these models allowing farmers to sow until 110% of the maximum surface observed in the last 10 years for these crops.

The data used to feed this model were modified with regards to the situation of the base year 2007, following the changes shown in Table 3. It is necessary to emphasise that with the aim of incorporating future constraints on pesticides in the model, crop costs and technical coefficients were modified with regard to the *PESTRISK* indicator. The pesticides that will be legally eliminated from the market have been considered, as well as those that farmers will be able to use as substitutes. These data were obtained through the survey of experts.

4.4. Modelling scenario "Triumph of the market"

The model constructed to simulate this scenario matched the previous one [model (6)]. However, the values of the parameters of change ($p_{i,j}$, $c_{i,j}$ and $s_{i,j}$) were modified in accordance with Table 3. Furthermore, in order to reflect the reduction in the environmental constraints on production that characterise this scenario, changes were made in the costs of pesticides and the technical coefficients for the *PESTRISK* indicator.

4.5. Modelling scenario "Regional sustainability"

In order to simulate the farmers' behaviour under the *Regional sustainability* scenario, the following model was defined:

$$Max\ TGM = \sum_i \sum_j \left\{ x_{i,j} \left[y_{i,j} p_{i,j} - c_{i,j} \left(\alpha_{i,j} + \beta_{i,j} x_{i,j} + \gamma_{i,j} \sum_j x_{i,j} \right) \right] \right\} + SFP_{reg} \qquad (7a)$$

Subject to:

Base model constraints: $A\vec{X} \leq \vec{B}$ (7b)

Sugar-beet abandonment constraint: $x_7 \leq 50\% \dfrac{\text{sugar-beet quota}}{\text{sugar-beet yield}}$ (7c)

Maximum nitrate application constraint: $\sum_i \sum_j (x_{i,j})\, NA_{i,j} \leq NALF_k \times SUR$ (7d)

Compulsory environmental set-aside constraint: $x_{11} \geq 3\%$ (7e)

The first difference with respect to the previous scenarios is the objective function modification, where SFP_{ind} was replaced by a regionalised single farm payment (SFP_{reg}), calculated on the basis of subsidies historically received by all irrigated agricultures in the county. Two new constraints, which reflect the increase in the environmental requirements for this scenario, were also incorporated. The first represents the imposition of nitrogen fertilization quotas [constraint (7d)], where NA_{ij} refers to the application of nitrogen for each crop, and $NALF_k$ is the nitrate application limit (for this scenario $k = 100$ kg N ha^{-1})[6]. The second constraint refers to the compulsory minimum 3% of the total farm area given over to environmental set-aside [constraint (7e)].

As in the other scenarios, the parameters of change shown in Table 3 were modified as appropriate. Likewise, production costs were adjusted to reflect the changes in the use of pesticides and coefficients to calculate the *PESTRISK* indicator were modified, according to the environmental requirements scenario with regards to the use of these products.

4.6. Modelling scenario "European sustainability"

The simulation model suggested for the *European sustainability* scenario is very similar to the previous one. In fact the objective function suggested for this scenario corresponds to equation (7a). The set of constraints proposed for this context are essentially the same as used in model (7):

Base model constraints: $A\vec{X} \leq \vec{B}$ (8a)

Sugar-beet abandonment constraint: $x_7 \leq 50\% \dfrac{\text{sugar-beet quota}}{\text{sugar-beet yield}}$ (8b)

Maximum nitrate application constraint: $\sum_i \sum_j (x_{i,j}) \cdot NA_{i,j} \leq NALF_k \times SUR$ (8c)

Compulsory environmental set-aside constraint: $x_{11} \geq 10\%$ (8d)

The only difference from model (7) regards the stricter environmental constraints. Thus, in this scenario the nitrogen fertilization quota was calculated by considering a value limit ($NALF_k$) of 80 kg N ha^{-1}, and the compulsory environmental set-aside rose to 10%.

As in the other models, the above-mentioned parameters of change were modified, as were pesticide product costs and the coefficients used to calculate the *PESTRISK* indicator.

4.7. Aggregated results at Irrigated Area level

The proposed modelling approach was developed for each homogeneous group of farmers derived from the cluster analysis. Hence, although the results obtained in first instance regard the individual results for each farm-type, the results were aggregated to cover all the scenarios, in order to obtain the results for the whole ID-AM. The farm-type results were aggregated by weighting the area represented by each of them.

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[7] The levels of these nitrogen fertilization quotas were chosen by considering that they have been used in previous works in the Duero basin (Gallego-Ayala and Gómez-Limón, 2009).

Table 4 – *Percentage variation of the sustainability indicators for each scenario*.

	Scenarios	***TGM*** **(€ ha^{-1})**	***PUBSUB*** **(€ ha^{-1})**	***EMPL*** **(Lab. ha^{-1})**	***SEASON*** **(%)**	***WATER*** **(m^3 ha^{-1})**	***NBAL*** **(kg N ha^{-1})**	***SOILCOV*** **(%)**	***EBAL*** **(kcal ha^{-1})**	***PESTRISK*** **(kg ha^{-1})**
1	***CAP-2005***	*424.55*	*226.38*	*1.93*	*46.5*	*3433*	*36.7*	*59.5*	*$1.42\ 10^7$*	*4489*
	CAP-reformed	58.3%	43.1%	-19.9%	3.8%	-32.5%	-31.4%	-1.8%	-24.8%	-45.7%
	Business-as-usual	12.7%	-3.3%	-21.9%	8.0%	-38.7%	-27.9%	0.2%	-26.3%	-73.5%
	Triumph of the market	-24.9%	-19.7%	-27.4%	10.5%	-48.5%	-34.7%	0.2%	-28.6%	-89.4%
	Regional sustainability	43.7%	14.6%	-20.8%	5.8%	-34.9%	-30.5%	-2.6%	-30.7%	-62.9%
	European sustainability	23.6%	27.6%	-28.4%	7.2%	-42.5%	-50.6%	-10.5%	-41.3%	-78.6%
2	***CAP-2005***	*483.13*	*188.99*	*2.02*	*47.9*	*3585*	*40.7*	*59.6*	*$1.67\ 10^7$*	*7111*
	CAP-reformed	63.9%	92.9%	-20.6%	5.3%	-41.9%	-41.0%	-3.1%	-34.7%	-51.8%
	Business-as-usual	21.6%	35.9%	-25.2%	13.1%	-54.4%	-38.2%	0.2%	-41.6%	-82.1%
	Triumph of the market	-27.7%	-18.1%	-29.0%	16.4%	-62.7%	-44.1%	0.2%	-44.0%	-94.0%
	Regional sustainability	43.9%	37.3%	-24.0%	10.1%	-49.3%	-36.7%	-1.8%	-42.5%	-71.7%
	European sustainability	23.7%	52.6%	-31.2%	12.1%	-60.8%	-54.6%	-8.4%	-55.8%	-90.2%
3	***CAP-2005***	*1159.72*	*28.38*	*2.73*	*65.1*	*7125*	*85.8*	*61.9*	*$4.29\ 10^7$*	*28864*
	CAP-reformed	21.8%	2,829.7%	-17.4%	-20.3%	-39.8%	-42.8%	-2.4%	-49.2%	-61.5%
	Business-as-usual	-14.9%	2,208.3%	-27.8%	-3.2%	-64.0%	-64.0%	-0.7%	-75.4%	-98.4%
	Triumph of the market	-54.3%	1,290.6%	-27.9%	-2.8%	-64.5%	-64.4%	-0.7%	-73.2%	-98.5%
	Regional sustainability	-45.2%	814.5%	-24.7%	-17.6%	-53.2%	-74.2%	-12.1%	-67.0%	-81.0%
	European sustainability	-55.4%	915.8%	-33.1%	-10.6%	-67.6%	-81.3%	-13.4%	-81.0%	-98.3%
A	***CAP-2005***	*457.47*	*211.12*	*1.97*	*47.3*	*3557*	*39.0*	*59.6*	*$1.56\ 10^7$*	*5781*
	CAP-reformed	59.2%	116.9%	-20.1%	3.7%	-35.4%	-34.5%	-2.2%	-28.3%	-47.8%
	Business-as-usual	14.7%	55.2%	-23.0%	9.3%	-43.9%	-31.7%	0.2%	-31.9%	-76.6%
	Triumph of the market	-26.4%	8.6%	-27.9%	12.0%	-53.0%	-38.1%	0.2%	-34.1%	-91.0%
	Regional sustainability	41.9%	38.3%	-21.9%	6.6%	-39.5%	-33.3%	-2.5%	-35.0%	-65.9%
	European sustainability	21.9%	53.8%	-29.4%	8.3%	-48.5%	-52.4%	-9.9%	-46.4%	-82.4%

5. Results

This section focuses on the analysis of the results for each proposed scenario at ID-AM level (see Table 4), since these are the most relevant to support the public-sector decision-making process. The individual results for each farm-type can be consulted in the same table.

5.1. Effects of the CAP reform scenario

With regards to the results of the *CAP-reformed* policy scenario, the first issue to be highlighted is that by the time that the implementation of the latest CAP reform is complete (decoupling subsidies and sugar CMO reform), farmers' profits will improve with respect to the existing situation in 2005 (*CAP-2005* scenario). This scenario can be expected to produce an increase of about 59.2% in the *TGM* indicator. Although the new crop plans are more extensive and have lower value-added (partial substitution of sugar-beet and irrigated winter cereals for rain-fed winter cereals), rises in the prices of agricultural products and the introduction of an individualised SFP will increase farmers' gross margins. In fact, it could be claimed that the decoupled farm subsidies through the SFP scheme would not balance the losses derived from the compulsory abandonment of sugar-beet, even though the public subsidies to agriculture (*PUBSUB* indicator) would rise by about 116.9% under the *CAP-reformed*. This growth in subsidies is due to the integration of sugar-beet into the SFP, derived from the last CMO sugar reform (substitution of the support via prices charged to the consumers by decoupled payments charged to the public budget).

On the other hand, implementation of this new agricultural policy scenario would have a negative impact on the *EMPL* indicator, due to a fall in the demand for labour of about 20.1%. Furthermore, the seasonality of labour demand by agriculture (*SEASON* indicator) would rise by 3.7%. These data confirm that the latest CAP reform will have a negative effect on the social role of agriculture.

From an environmental point of view, the *CAP-reformed* scenario will have a positive impact on irrigation water consumption (decrease in *WATER* indicator of about 35.4%), the liberation of nitrogen into the environment (reduction in *NBAL* indicator of about 34.5%), and pesticide toxicity (variation in *PESTRISK* indicator of about 47.8%). On the other hand, there will be a negative effect on the energy balance and the risk of soil erosion (falls in *EBAL* and *SOILCOV* indicators of about 28.3% and 2.2% respectively).

5.2. "Business-as-usual" scenario

The *Business-as-usual* scenario would have a positive effect on farmers' profitability, in comparison with the *CAP-2005* scenario situation. Thus, the *TGM* indicator would increase by about 15%, even with the spread of production (partial substitution of sugar-beet and maize for rain-fed crops). This is due to the implementation of SFPs and the integration of sugar-beet into them, as well as to the higher prices obtained than those under the baseline scenario (although lower than those existing in 2007). Nevertheless, the rise in profitability is less than in the *CAP-reformed* scenario, because of the proposed budgetary restrictions (*PUBSUB* indicator growth of about 55.2%, as opposed to more than 100% in the previous scenario) and prices would drop below 2007 levels.

On the other hand, this scenario would have a negative impact on the viability of rural communities in the ID-AM. Thus, the demand for labour would decrease by about 23%, as a consequence of expansion in crop production (introduction of rain-fed crops which demand less labour), and a more concentrated distribution of work throughout the year (increase in the *SEASON* indicator of about 9.3%).

From an environmental point of view, the impact of this scenario, like that of the previous one, is equally positive for most of the indicators analysed. Improvements can be expected in the values of *WATER*, *NBAL* and *PESTRISK* (reductions of 43.9%, 31.7% and 76.6% respectively) from which we can deduce that the local environment will improve (reduced quantitative and qualitative impacts on the groundwater sources which supply the ID-AM). However, the energy balance (*EBAL* indicator) would decrease by about 31.7%, which would lead to a reduction in the capture of CO_2 with, in turn, a negative effect on climate change (global environment). Finally, this scenario would have only a minor effect on soil cover (*SOILCOV* indicator).

5.3. "Triumph of the market" scenario

The simulations made for the *Triumph of the market* scenario show an important decrease in the *TGM* indicator (-26.4%) vis-à-vis that obtained under the *CAP-2005* baseline scenario. This could jeopardise the viability of a significant number of farms, particularly small units whose main crop is sugar-beet. This loss in profitability would be caused by a combination of different factors: a) the fall in prices of agricultural products as a consequence of market liberalization, b) the rise in the price of energy and inputs, and c) budgetary restrictions on agricultural subsidies. With regards to the latter, the *PUBSUB* indicator would face a slight increase (+8.6%) with respect to the situation in 2005. Nonetheless, it should be emphasised that the subsidies received by farm-types G1 and G2 would be reduced by 19.7 and 18.1%, respectively. Only the homogeneous groups labelled as *small sugar-beet growers* would receive more support than under the *CAP-2005* scenario; but this would not be sufficient to compensate for the losses caused by the compulsory abandonment of sugar-beet and the other above-mentioned factors.

On the other hand, where social indicators are concerned, this scenario would generate an important decrease in the demand for labour by irrigated agriculture (*EMPL* indicator fall of 27.9% with respect to the baseline scenario) and a rise in seasonal labour employment (increase in *SEASON* indicator of about 12.0%). The growing importance of winter cereal crops with respect to the 2005 situation, which would cover as much as 85% of the area of the ID-AM, would cause this negative impact on rural development (encouragement of rural exodus).

To conclude this scenario, the *Triumph of the market* would produce significant decreases in the demand for irrigation (*WATER* indicator fall of 53.0%), in nitrate fertilisers leached into the environment (*NBAL* indicator fall of 38.1%) and in releases of pesticide toxins (*PESTRISK* indicator drops at 91.0%) all as a consequence of the extension of crop plans. In contrast, as in the above-mentioned cases, the spread in production which characterises this scenario would imply a worsening of the energy balance (*EBAL* indicator would decrease by about 34.1%), which in turn would reduce the capture of greenhouse gases by the agricultural system. Finally, this scenario would produce a slight variation in the *SOILCOV* indicator.

5.4. "Regional sustainability" scenario

Table 4 shows that the simulation models for the *Regional sustainability* scenario would have a positive effect on farmers' profitability. Indeed, the *TGM* indicator would display an increase of about 41.9%, due both to the rise in the selling price of products and to the maintenance of public support, which in this scenario, would take the form of a regionalised single payment (based on cultivated area, regardless of what is grown). However, it is necessary to modify the optimism of the previous results, since the positive impact on *TGM* indicator is not shared equally among all the different farm types in the ID-AM. Indeed, although farm-types G1 and G2 would greatly benefit from this scenario, the opposite would be the case for the homogeneous group labelled as *small sugar-beet growers* (a fall in *TGM* of about 45.2%). Such an unequal impact over net income would be produced by the application of the regionalised SFP, which would significantly penalise sugar-beet growers (a crop that received higher subsidies via prices under the *CAP-2005* scenario and generated higher SFP rights per unit area under the *CAP-reformed* scenario) in contrast to cereal growers, who would be favoured by this new scheme of decoupled subsidies.

This scenario would have a negative social impact in that it would produce a decrease in demand for labour of about 21.9%. As in other scenarios, the decrease in the *EMPL* indicator is caused by changes in production plans, characterised by an increase in the area devoted to rain-fed crops and the introduction of compulsory environmental set-aside, activities that are less labour-intensive. Furthermore, a slight increase (6.6%) in seasonality (*SEASON* indicator) vis-à-vis the baseline scenario *CAP-2005* can be seen.

On the other hand, this scenario would have a positive impact on environmental indicators, since it would reduce the *WATER*, *NABL*, *PESTRISK* indicators by about 39.5%, 33.3% and 65.9% respectively. This would produce important savings in water resources, reduce the risk of diffuse nitrate pollution of water resources and lower emissions of environmental toxins by agriculture. The *NBAL* and *PESTRISK* indicators would thus be significantly improved due to more extensive crop plans (introduction of rain-fed crops and environmental set-aside), as well as to the implementation of stricter requirements regarding the use of fertilisers (nitrate fertilization quotas) and pesticides (ban on certain active components and their substitution by other safer substances).

Nevertheless, and still from an environmental perspective, the negative impact of this scenario on energy balance and soil cover should also be emphasised. The *EBAL* and *SOILCOV* indicators would decrease by about 35.0% and 3.3% respectively, which suggest reduced energy efficiency and an increased risk of soil erosion.

5.5. "European sustainability" scenario

The results of the *European sustainability* scenario show an increase in farm profitability, with respect to the baseline scenario situation (a *TGM* growth of about 21.9%). As in the previous case, this improvement is due to high agricultural prices and farmers´ subsidies (regionalised SFP). However, as in the *Regional sustainability* scenario, the implementation of regionalised SFPs would involve a noticeable loss for the G3 farm-type (*small sugar-beet growers*), with a fall of more than 55% in the *TGM* indicator, since the uniform payment per hectare is disadvantageous for them.

This scenario would have a negative social effect as it would both decrease total labour demand (*EMPL* indicator reduction around 30%) and increase seasonal labour demand (*SEASON* indicator rise of 8.3%). Both of these aspects would be caused by the introduction of the rain-fed production (winter cereals and rain-fed sunflower) crop-mix and the compulsory use of 10% of the farm for environmental set-aside, both of which are less labour-intensive than irrigated crops (sugar-beet, maize, etc.).

To conclude, this scenario would have a positive impact on the water use (down by 48.5%), nitrate balance (down by 52.4%) and pesticide risk (82.4% less) indicators. As we emphasised in the previous case, besides the spread of the crop-mix production plan, this positive trend is marked by the introduction of nitrogen fertiliser quotas and the ban on certain components of pesticides, due to the scenario's stricter environmental requirements. On the other hand, same scenario would lower the energy efficiency of the agricultural system (CO_2 capture), with a reduction in *EBAL* indicator of about 46.4%. Moreover, it would increase the risk of soil erosion due to a reduction in the number of days per year on which the soil is covered by crops (*SOILCOV* indicator would fall by about 9.9%).

6. Concluding remarks

Our results demonstrate the potential utility of this type of prospective study. Indeed, it shows how each scenario would have specific economic, social and environmental impacts on each of the agricultural systems analysed. These results can be useful because they enable to reflect in some depth on the design and implementation of policies that affect the agricultural sector (i.e. CAP reforms, WFD implementation, etc.). In fact, an in-depth analysis of the variation of sustainability indicators calculated would thus allow us making better judgments about the pros and cons of each of these scenarios in our near future, that could be synthesised through a hierarchy of scenarios on the basis of their relative social desirability. However, such prioritisation lies out with the technical and scientific scope of this work (for this purpose normative or political criteria are needed), reason for which nothing can be pointed out in line with this. In any case, if such a hierarchy were to be established as a support for political decision-making, it would have to take account of the opinions of citizens and/or their political representatives in any search for an alternative scenario that maximises the welfare of society as a whole. According to this arrangement, which would be based on social desirability, the ultimate goal of public representatives would be to facilitate the occurrence of the "best" scenario possible through the implementation of the most adequate policies. Thus, the final objective of this kind of prospective analysis is the support of current public decision-making in order to channel agricultural systems into a desirable future.

A more detailed analysis of the results leads us to the conclusion that certain tendencies are shared by all the scenarios, which are less under the control of political action. All the scenarios considered here would thus encourage the spread of agricultural production (substitution of the most intensive crops, such as sugar-beet or maize for other less intensive crop plans such as winter cereals, whether irrigated or rainfed). Such a trend in production would lead to a deterioration of the social role of agriculture in rural areas (a decrease in the overall demand for labour accompanied by a concentration of the demand for labour during certain seasons of the year), while, on the other hand, it would improve the environmental sustainability of irrigated agriculture (decrease of negative externalities; consumption of irrigation water, diffuse pollution by nitrates and toxic effects of pesticides).

Most scenarios (with the exception of *Triumph of the market*) imply an improvement in the profitability of irrigated farms in this area. However, this finding is essentially based on increased prices for agricultural products, which has been assumed for all the future scenarios relative to the baseline scenario (*CAP-2005*), to a greater or lesser extent. The scenario of high prices would ensure that the profitability of the farms analysed is not excessively affected by reductions in public support to the agricultural sector or by stricter environmental requirements. If the premise of high prices is not fulfilled, the economic viability of this agricultural system would be compromised, making any change in the agricultural policy in the direction of budgetary austerity and/or environmental sustainability more difficult.

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