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The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models

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Abstract

The objective of this paper is to evaluate the impacts of agriculture and water policy scenarios on the sustainability of selected irrigated farming systems in Italy, in the context of the forthcoming implementation of the directive EC 60/2000. Directive EC 60/2000 (Water Framework Directive) is intended to represent the reference norm regulating water use throughout Europe. Five main scenarios were developed reflecting aspects of agricultural policy, markets and technologies: *Agenda 2000, world market, global sustainability, provincial agriculture* and *local community*. These were combined with two water price levels, representing stylised scenarios for water policy. The effects of the scenarios on irrigated systems were simulated using multi-attribute linear programming models representing the reactions of the farms to external variables defined by each scenario. The output of the models consists of economic, social and environmental indicators aimed at quantifying the impact of the scenarios on different aspects of sustainability relevant for irrigated farming systems. Five Italian irrigated farming systems were considered: cereal, rice, fruit, vegetables and citrus. The results

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show the diversity of irrigated systems and the different effects that water pricing policy may produce depending on the agricultural policy, market and technological scenarios. They also highlight a clear trade-off between socio-economic sustainability and environmental (water, nitrogen, pesticide) sustainability. Water pricing will have, in most cases, less impact than agricultural markets and policy scenarios, though it appears to be an effective instrument for water regulation in the least intensive irrigated systems considered. This emphasises the need for a differentiated application of the Water Framework Directive at the local level as well as a more careful balance of water conservation, agricultural policy and rural development objectives.

Keywords: Water Framework Directive; Common Agricultural Policy; Irrigation; Multi-Attribute Analysis; Linear programming; Sustainability indicators

1. Background and objectives

Irrigated farming systems play a major role in Italian agriculture. In spite of the increasing irrigable area, the use of water in agriculture decreased in relative and absolute terms during the 1990s, due to the concurrent effects of improved irrigation technology, shortages of water during this period (with frequent droughts during the summer, often leading to a halt in water distribution) and the economic difficulties of irrigated agriculture.

The future of irrigated systems will be heavily affected by the trends in European water and agricultural policy, as well as by their interplay with the development of global agricultural markets and technology trends (Gómez-Limón et al., 2002).

Major changes in the regulatory context concerning water management are expected because of the implementation of the Water Framework Directive (WFD) (OJ, 2000). The WFD establishes the legal framework for the regulation of water use in Europe. WFD implementation will pass through different phases and should be completed in 2012 in order to achieve a "good ecological status" of water by 2015. Among other things, it calls for the application of economic principles to water management policies, on different bases. First of all, it introduces the principle of full cost recovery (FCR). According to this principle, water users should bear all the costs of water provision. To this aim, the full cost (FC) is defined as the sum of financial, resource (intended as the opportunity cost due to water subtraction from alternative uses) and environmental costs of water use. The inclusion of the last item is motivated by the adoption of the polluter pays principle (PPP) in the WFD. Also, the WFD requires the use of economic analysis to define ex-ante the measures to be adopted and encourages the provision of economic incentives to water users (e.g. through water pricing), in order to stimulate water saving (WATECO, 2003).

Despite the relatively little attention it has received in Italy up until recently, the WFD could bring about major changes in irrigation management. The extreme hypothesis of FC recovery and volumetric pricing would radically change the structure of water pricing that, presently, is mostly based on area tariffs, with cost recovery limited to a share of financial costs.

An even stronger impact may be expected from the ongoing reform of the European Union (EU) Common Agricultural Policy (CAP). CAP has strongly affected agricultural markets and incomes in Europe since its inception in 1957, through prices and direct income support. The CAP underwent major changes through Agenda 2000 and the 2003 reform. Both of them change CAP in the direction of a reduction of payments, of a decoupling of public support from production and of an increase in the multifunctional role of agriculture. In spite of the fact that the present CAP framework is designed to last until 2013, further reforms are expected to intervene even before that date. CAP mainly affects incentives for water use by determining the differential in profitability between irrigated and rainfed crops, as well as by affecting the marginal profitability of water use in irrigation. Both of these effects will be influenced by decoupling and changes in price support.

Future trends in CAP and agricultural markets, on the one hand, and water policies, on the other, will interact to jointly affect the viability of irrigated farming systems.

The objective of this paper is to evaluate the impact of expected changes in water policy (with particular reference to the WFD implementation) on the economic, social and environmental sustainability of selected irrigated agricultural systems in Italy, under different agricultural policy, market and technological scenarios.

It is relatively common in the literature to consider partially these issues, by analysing the reaction of irrigated agriculture to some specific parameter, e.g., water price or CAP payments (see papers cited in Section 3). The research described in this paper adopts a partially different approach, by attempting to consider the reaction of irrigated systems to consistent scenarios that include all the main relevant parameters of CAP, agricultural markets and water technology. Preliminary results of this research can be found in Bazzani et al. (2005) and Gallerani et al. (2004). With respect to such papers, this article develops further the analysis by coupling the aforementioned scenarios with different hypotheses about water pricing levels, in order to evaluate the interplay among the two sets of variables composing the overall context of irrigated agriculture.

Effects of scenarios are estimated using multi-attribute linear programming models simulating the reactions of farms to external variables (prices, technology etc.). The results, from the perspective of WFD and CAP reform, are evaluated through a set of indicators aimed at representing the economic, social and environmental performances of irrigated systems.

In Section 2, the issue of the connection between WFD and irrigated agriculture in Italy is further explored. Section 3 illustrates the methodology and describes the study areas, model validation and scenario analysis. The results are illustrated in Section 4 and discussed in Section 5.

2. WFD, CAP reform and agricultural water management

In 2000, irrigated agriculture in Italy covered about 29% of usable farmland and 40% of farms; it also accounted for about 50% of the total national water use (INEA, 2000; ISTAT, 2002). While irrigation is most common in the north, due to higher water availability, it tends to be a crucial issue in the south, where traditionally important productions may be cultivated only where irrigation is possible (e.g. citrus, vegetables). Italian agriculture, under the umbrella of the CAP, is characterised by a high degree of public intervention guided by a complex mix of political, economic, social and environmental objectives. CAP is also a major determinant of the sustainability of irrigated systems. CAP and water policy objectives sometimes appear contradictory, as in the case of irrigated cereals, where CAP payments are associated with irrigated crops (typically maize), and thus encourage higher water consumption. In other cases they may be perceived as synergistic, when they are associated with rainfed crops (e.g. wheat), and thus may encourage a shift from irrigated to non-irrigated agriculture.

In recent years the CAP has been promoting the multifunctional role of agriculture. Agriculture is seen more and more as an activity producing a complex set of interconnected outputs to be evaluated, at the same time, under an economic, social and environmental perspective. The economic role of agriculture is to be identified with the ability to provide economic value through the traditional function of the production of food and fiber. From a social point of view, agriculture is perceived as a sector able to maintain local culture, employment and population in otherwise (potentially) abandoned areas. From an environmental point of view, agriculture produces negative externalities, including those related to water quality such as nitrogen emissions, as well as positive externalities, such as landscape and related services. Since the end of the 1980s, specific policies have been in place in order to reduce the negative externalities and increase the positive externalities produced by agriculture.

Recent CAP reforms (Agenda 2000 and the 2003 reform), while maintaining these objectives (particularly through rural development measures, such as the so-called "second pillar" of CAP, and cross compliance measures), adopted more market-oriented instruments, such as the decoupling of payments. These reforms have come at the same time as recurrent market crises for many irrigated and non-irrigated crops (in 2005, fruit and vegetables have more or less the same prices as in 1995; the price of cereals in 2005 is about 70% of that in 1997). At the same time, the upturning trend in production costs appears to continue (source, ISMEA – Istituto di servizi per il mercato agricolo alimentare).

Water policy has traditionally been a key promoter of irrigated agriculture, through the provision of subsidised water thanks to state funding of water storage and transport infrastructures. Presently the water distribution system in Italy is mainly managed by "Reclamation and Irrigation Boards" (RIB). They are organised as associations of farmers that control the management and distribution of water resources for agricultural purposes over a certain area. They also provide land reclamation and flood defence services. In a few minor cases, they also contribute to water delivery for non-agricultural purposes. Water use regulation is based on a complex system of locally specific property rights. Water pricing works usually through area-based tariffs aimed at covering the operational costs of RIBs. Investment costs (borne by the state) are not considered, let alone opportunity and environmental costs. No clear aim of water saving is usually assumed. There are examples of volumetric pricing, associated with the most recent pressure pipe distribution systems, in which water metering is possible.

Changes in water regulation brought about by the WFD will likely be reflected extensively in the management of irrigation water, though application is differentiated at the local level, on the basis of river basins. Irrigated agriculture is a key node in the implementation of WFD, particularly in Mediterranean countries. In these regions agriculture accounts for the greatest share of water use (between 50% and 80% of the total), but is often characterised by a very poor water use efficiency. Side effects of irrigation, such as pollution from fertilisers and pesticides, as well as its benefits related to soil and landscape management make the role of irrigated farming systems even more relevant for water conservation objectives.

One of the main concerns connected with the implementation of the WFD is the expectation that the application of the FCR will cause a net increase in water prices. This expectation is motivated by the fact that a rigid application of the FCR will require that we add to the present water price the capital (depreciation and interest) cost of investments, the opportunity cost of water and the environmental cost.

The impact on water pricing structure could also be an issue, due to the fact that the WFD encourages the use of economic instruments, such as volumetric pricing, for water regulation. This raises questions about the reaction of farming systems to volumetric pricing and the consequent desirability of using such instruments as tools for water policy.

In addition, the use of economic analysis in ex-ante decision making about water regulation measures may represent a potential threat to agriculture, due to its low economic relevance compared with other sectors. Economic analysis in itself could suggest a reallocation of scarce water away from agriculture if the decision is based on mere economic criteria.

The timing and the extent of application of the WFD principles in Italy are still uncertain. The WFD itself provides for a gradual implementation of these concepts and allows for motivated derogations, i.e. cases where the principles of the directive can be not or only partially implemented, subject to justification. As a matter of fact, volumetric water pricing and full cost recovery are often considered important principles in order to achieve sustainable water management, but they are seldom applied in practice for efficiency or equity reasons (Dinar and Subramanian, 1997; OECD, 1999).

In view of the widening discussion about implementation of the WFD in Italy, it appears particularly relevant to provide an evaluation of the effects of alternative water policy strategies (in particular concerning pricing) under different agricultural policy, market and technology scenarios. It appears also necessary to measure the outcome with respect to the different aspects of sustainability as defined by EU farming and rural policy discourse, i.e. a consistent set of economic, social and environmental indicators.

3. Methodology and case studies

3.1. Overview

The methodology is intended to simulate the impact of agriculture and water policy scenarios on defined agricultural systems of selected study areas. For the purposes of this study, an agricultural system is taken to be a form of farming defined by a given crop combination and located in a given RIB. According to this definition, an irrigated farming system does not represent a watershed, nor does it fully cover an agricultural area. Instead, it represents a set of farms with a similar productive specialisation that are mixed with others not considered in the analysis.

The methodology is based on the following steps: (1) selection of relevant farming systems; (2) identification of representative farm types; (3) modelling of farm types; (4) definition of agricultural and water policy scenarios; (5) simulation of the impacts of different scenarios on the performance of the farm and (6) aggregation of the results for each farming system.

3.2. Selection of relevant farming systems

Five irrigated agricultural systems have been selected: a cereal system – Mantua Lombardy region, Northern Italy (RIB Fossa di Pozzolo); a rice system – Ferrara, Emilia Romagna region, Northern Italy (RIB I Circondario Polesine di Ferrara); a fruit system – Ravenna, Emilia Romagna region, Northern Italy (RIB Romagna Occidentale); a vegetables system – Foggia, Apulia region, Southern Italy (RIB Capitanata); a citrus system – Syracuse, Sicily region, Southern Italy (RIB Piana di Catania).

Farming systems have been selected as representative of the main Italian irrigated crop specialisations (extensive and intensive), as well as of different geographical and climatic conditions (northern and southern Italy). The main features of the study areas, and the way in which case studies have been selected, are illustrated in Table 1.

The cereal system case study represents a variety of extensive farming (maize, wheat, protein and fodder crops), traditionally based on average to high water use and benefiting from considerable public support. Small amounts of melons and watermelons are also cultivated. The area is traditionally characterised by plentiful water availability.

The rice system case study involves an area close to the Po delta. Water is readily available, but there are also strong agronomic constraints due to peaty soils that require the cultivation of rice over at least half of the farm area, in order to maintain those soil characteristics compatible with farming. For this reason, such a system is representative of the vulnerability of farming in high water-consuming, but economically marginal, areas.

In the case study featuring the fruit system, farming mainly involves the cultivation of peaches, wine grapes and kiwi fruit. The fruit system is traditionally considered to be one of the most profitable and strong farming systems in Italy. In fact, it is a system producing high added value, is backed by a strong marketing organisation, and mostly involves co-operative commercialisation.

Table 1
Main features of the five study areas

	Agricultural system				
	Cereal	Rice	Fruit	Vegetables	Citrus
Water supply	Po River	Po River	Emilia Romagna Canal	Dams, Ofanto River, private wells	Dams, Simeto River, private wells
Water distribution system	Open canals	Open canals	Pressure pipes, open canals	Pressure pipes	Pressure pipes
Irrigation system	Mobile wings, sprinklers	Flood system, infiltration	Drip irrigation	Drip irrigation	Drip irrigation, sprinklers
Water price	0.12 euro/m^3	0.016 euro/m^3	0.15 euro/m^3	0.09 euro/m^3	0.31 euro/m^3
Prevailing tariff system	Area based	Volumetric	Volumetric	Volumetric	Volumetric
Agricultural area in the RIB (ha)	48,137	91,085	193,359	143,000	98,000
Agricultural area of the system (ha)	27,919	11,582	21,675	25,740	14,700
Main crops	Maize, soy, sugar beet	Maize, soy, sugar beet, rice	Peach, nectarine, wine grape	Durum wheat, tomato, broccoli	Orange

The case study of the vegetable system features a combination of high-income tomatoes and highly-subsidised traditional crops such as non-irrigated durum wheat, sometimes supplemented by other vegetables. The development of high-added-value crops is counterbalanced by a high environmental impact, and is dependent upon the sufficient availability of water.

Finally, the citrus fruit case study involves a highly-specialised, intensive system based in southern Italy. It is representative of the rich, but fragile, Mediterranean agricultural systems heavily dependent upon water availability but with a very high level of water consumption. Oranges represent the main crop.

3.3. Identification of representative farm types

Farm typologies in each study area were selected on the basis of cluster analysis. The cluster analysis was intended to gather farms within relatively homogeneous groups in order to account for heterogeneity between (groups of) farms using a limited number of models (Day, 1963; Gómez-Limón and Riesgo, 2004). The cluster analysis has been applied on secondary data derived from available data sets (e.g. land registers held by irrigation boards). A hierarchical cluster algorithm (Ward method) (Ward, 1963) was applied to each area database employing standardized variables while ANOVA was used to test the significance of each discriminant variable (crop mix and farm size). The dimension of the database for the fruit farming system did not allow the use of this hierarchical algorithm on the whole sample. For this reason it was applied on a random sample (150 observations), and the number of clusters was derived on the basis of the dendrogram. Knowing this number, farm clusters were then identified using a non-hierarchical algorithm (*k*-means) on the whole database.

Once identified, clusters were validated through informal interviews (one to three interviews in each case study area) with local experts (representatives of irrigation boards and farmers organisations,). On a sample of farms stratified on the basis of the clusters, a further analysis has been carried out through face to face interviews, in order to collect information about structural data (e.g. labour organisation), crop mix, and technical and economic information on the production processes (see model calibration).

The main characteristics of the sampled farms are described in Table 2, together with the number of clusters for each irrigated farming system.

Table 2
Main characteristics of the sampled farms

Agricultural system	Area in the sample (ha)	Number of farms in the sample	Average farm size in the sample (ha)	Number of clusters modelled
Cereal	1105	26	42.5	1
Rice	6093	86	70.8	2
Fruit	6086	1479	4.1	4
Vegetables	913	120	7.6	2
Citrus	187	16	11.6	2

3.4. Modelling of farm types

Each cluster has been modelled separately and the results were aggregated at a later stage (step 6). The methodology adopted for modelling is based on multicriteria mathematical programming. Mathematical programming techniques are widely applied in agriculture (Hazell and Norton, 1986) and a large body of literature exists focusing on the use of such tools for irrigation problems (see for example Varela-Ortega et al., 1998; Amir and Fisher, 1999; Garrido, 2000; Berbel and Gómez-Limón, 2000). An issue relevant to the accuracy of these models concerns the assumptions they make about decision maker's objectives. In order to represent the complexity of such objectives, multicriteria analysis seems more flexible and comprehensive than the simple profit-maximizing approach (Romero and Rehman, 2003; Rehman and Romero, 1993). For this reason, it has been used by some authors for the modelling of irrigated agricultural systems where multiple private objectives can affect farmers' behaviour (Gómez-Limón and Berbel, 2000; Gómez-Limón and Arriaza, 2000; Gómez-Limón et al., 2002). A number of multicriteria approaches have been proposed and used in order to analyse decision making problems related to farming systems (Hayashi, 2000). This study adopted a multi-attribute utility theory (MAUT) approach (Keeney and Raiffa, 1993; Ballestero and Romero, 1998). The utility function was assumed to be linear, since it has been shown that this method may yield results close to reality while considerably simplifying the models (Hwang and Yoon, 1981).

The model runs as a standard linear programming model, with a multicriteria objective function of the form:

$$\text{Max } U = \sum_j w_j r_j$$

where U (utility) is the value of the objective function, w_j is the weight of attribute j and r_j is the value of attribute j. The value of each attribute derives from the activities carried out on the farm (crops, irrigation levels, irrigation plants, etc.) and is calculated as

$$r_j = \sum_i a_{ij} x_i$$

where a_{ij} is the coefficient of the attribute j for the activity i and x_i is the activity level. The a_{ij} quantify the change in the value of attribute j as a result of a unit increase of activity i. The model is constrained to

$$\sum_i c_{ki} x_i \leqslant C_k \quad \text{and} \quad x_i \geqslant 0$$

where c_{ki} represents the technical coefficients (technical coefficients quantify the use of resources due to a unit increase of activity i), while C_k represents resource availability (labour, land) as well as additional agronomic and commercial constraints depending on their relevance for each single case.

Models were calibrated on a mix of secondary and primary data collected through the survey. Reference product prices and yields were calculated as the average of the last 5 years available (1999–2004). Technical coefficients and rotation constraints were estimated through interviews with local experts. Resource availability (land, labour) was estimated as the average for each cluster.

The selection of the relevant objectives and the estimation of the related weights were conducted following the methodology proposed by Sumpsi et al. (1996) and Berbel and Rodríguez-Ocaña (1998), who suggested a weighted goal programming aimed at minimizing the distance between model results and observed farmers' choices. Operationally, weight coefficients were determined as those minimising the sum of the distances between actual and simulated crop mix. This also represents the main criterion for the validation of the model.

The main objectives identified are connected with farm income, crop diversification and labour management. A first list of objectives was drawn from the literature and enriched through objectives self declared by the farmers interviewed. Income objectives may be represented by farm income or "pure" profit. An indicator of farm level crop diversification was adopted in order to deal with farmer behaviour in the face of commercial and climatic uncertainty. It is quantified by the complement to 1 of the sum of the positive distances from an equal distribution of land to each crop, within each farm. Labour management has to do with the objectives of containing the employment of external labour and reducing family labour on the farm, both measured in hours of labour required The relevance of different decision making attributes (w_j) appears to be rather different in different farm types (Table 3).

This corroborates the assumption that different farm objectives affect irrigation and farm management choices. However, farm income (or profit) prevails in most

Table 3
Attribute weights and validation of farm models

		Objective						Validation[a] (%)
		Max net income	*Max profit*	Max differentiation	Min total labour	Min family labour	Min external labour	
Cereal	Cluster 1	0.87	0	0	0	0	0.13	7.3
Rice	Cluster 1	0.84	0	0	0.16	0	0	20.5
	Cluster 2	0.82	0	0	0.18	0	0	21.2
Fruit	Cluster 1	0.77	0	0	0	0.23	0	25.3
	Cluster 2	0.89	0	0	0	0.11	0	32.0
	Cluster 3	0.22	0	0	0	0.04	0.74	17.2
	Cluster 4	1.00	0	0	0	0	0	9.9
Vegetables	Cluster 1	0.00	0.57	0.13	0.30	0	0	29.5
	Cluster 2	0.90	0	0	0.10	0	0	17.1
Citrus	Cluster 1	0.83	0	0	0	0.17	0	0
	Cluster 2	0.66	0	0	0.33	0	0	0

[a] Sum of the differences between the model and the actual crop mix.

cases. Among other objectives, labour minimisation plays a major role, particularly for intensive farms (fruit and vegetables).

According to the methodology adopted, model validation was attained at the same time as weight estimation, as the weights were estimated by minimising the differences between the model and the actual behaviour of farms, described by the combination of farming activities. The validation indicator is the sum of absolute differences between the actual crop mix (independent of the data used for calibration, except the weights) and that produced by the model.

3.5. Definition of agricultural and water policy scenarios

The data coming from the scenario analysis were fed into the models, once they were constructed and validated. Scenarios are intended to represent combined agriculture and water policy futures. Scenarios have been developed following a general framework developed by Berkhout et al. (1998) and existing scenarios on water use in agriculture (OECD, 1999; Kroll, 2001), and were adapted to the problem under analysis through internal discussion with the partners in the project "Sustainability of European Irrigated Agriculture under Water Framework Directive and Agenda 2000 (WADI)" (Berbel and Gutierrez, 2004). Scenarios have been further adapted to the Italian situation, with differentiation by farming system (particularly as far as specific environmental conditions, productive features, quality strategy and self-sufficiency issues are concerned).

Five scenarios were considered: *agenda 2000 (A2000), world market (WM), global sustainability (GS), provincial agriculture(PA)* and *local community(LC).*

In 2001 there were modifications in the CAP of the European Community. This package of modifications was named Agenda 2000 and stayed in place up to implementation the 2003 reform in 2005. *Agenda 2000* represents the base run scenario, built on prices, agricultural policy and farm characteristics at 2001, assuming they remain the same up to 2010. The other four scenarios derive from combinations of prevailing values and the levels of governance, which are recognised as the two main driving forces behind possible futures. *World market* describes a scenario characterised by a high degree of liberalisation, where decisions are taken through market mechanisms at the global level. In the *provincial agriculture* scenario, choices are guided by markets, but they work on a regional scale. In the other two scenarios, decisions are taken on the basis of community values, which may work at the global (*global sustainability*) or local (*local community*) levels.

The time horizon for scenario definition was taken to be 2010. Firstly storylines were developed, followed by the quantitative definition of scenario parameters. Scenario parameters include agricultural products prices, technical coefficients (e.g. water use efficiency), and the proportion of each farm type in each farming system (Table 4). They were identified with the aid of interviews with 12 experts representing different agriculture-related actors from different parts of Italy, while five representatives of the relevant irrigation boards were interviewed about water prices and related issues.

Table 4
Main quantitative assumptions by scenario

	Scenario				
	Agenda 2000, %	World market, %	Global sustainability, %	Provincial agriculture, %	Local community, %
Crop price					
Cereals	100	85–95	80–100	100–105	105–120
Rice	100	50	70	110	120
Vegetables	100	85–95	105–110	100	110–120
Fruit	100	85–95	95–100	100	105–125
Industrials	100	75–80	90–95	90–100	105–120
Payments					
Payments cereals and set aside	100	0	80–100	100–105	90–105
Set aside area	100	0	95	100	105
Payments no food crops	100	0	90–95	85–95	85–105
Input price					
Chemicals input	100	90	135–140	105	140–160
Energy and fuel	100	90	150	110	160
Seeds	100	120	105	115	100
Machinery	100	85–90	120–125	100–105	130–135
Contractor services	100	100–105	110–115	120–125	130–135
Labour	100	110–120	125–140	110–120	130–135
Other inputs	100	95	105	100	115
Water and irrigation					
Irrigation efficiency	100	120–200	145–215	130–200	135–205
Other effects					
Input use by hectare	100	110	95	100	90
Crop yield	100	100–120	95–115	100–110	85–95
Farm size	100	130–170	110–140	110–130	100–110
Labour availability	100	120	115	100	90
Labour requirement by hectare	100	95	100	100	105

Prices of farm products are generally expected to decrease, while prices of inputs are expected to increase, with the exception of the case of *world market*. Payments due to the CAP are expected to disappear in the *world market* scenario, and to decrease in the others, with the main exception of the *local community* scenario. Irrigation efficiency is expected to increase reflecting increased pressure on water issues and induced technology improvement. Changes in yields and input use reflect the trends toward more input intensive/efficient farming systems. Exceptions are represented by *global sustainability* and, more strongly, by *local community*, where significant input use and yield reductions are expected to be pursued in order to serve local environmental and social objectives.

In order to estimate the separate impacts of water pricing and agricultural policies and market and technological scenarios, each scenario has been evaluated under two alternative water price levels, corresponding to the present price and twice the present price. Such levels, according to experts interviewed, may represent a reasonable range of increase in the water price if the WFD principles have to be put in place. Volumetric pricing was assumed in all cases.

3.6. Simulation of the impacts of different scenarios on the performance of a farm

The impacts of different scenarios are quantified through a set of economic, social and environmental indicators developed on the basis of OECD (2001) (Table 5).

Economic indicators are used to assess the possible effects of scenarios on the economic sustainability of agriculture. The social aspect of agriculture is revealed by farm employment. Water use, the emission of nutrients and the use of pesticides are adopted as environmental indicators, as they correspond to some of the main pollution concerns connected to agriculture, are directly related to the pollution of water resources and are easily measurable at farm level. In order to make results comparable across farming systems, indicators are expressed per hectare of usable farmland.

Farm profit is defined as the difference between the value of gross output and all expenses, including fixed costs such as capital costs (depreciation and interest) and general expenses. This indicator is one of the key indicators of the long-term sustainability of agricultural systems. If financial returns are consistently negative, then any farming system will be unsustainable, unless supplemented by other sources of income. With respect to this issue, profit is different from household income, which can include revenues from non-agricultural activities and/or revenue from different production factors employed on the farm and subtracted from profits (labour, capital). As this is often the case, production systems may survive even with negative profit, assuming the willingness of farmers to accept a certain under-remuneration of some production means.

Farm contribution to GDP has been estimated as the added value produced at farm level, i.e. the difference between total revenue and intermediate consumption.

Table 5
Selected indicators for the measurement of the different aspects of sustainability

Aspect of sustainability	Sub-aspect	Selected indicators
Economic		Farm profit
		Farm contribution to GDP
Social		Farm employment
Environmental	Biodiversity	Genetic diversity
	Water use	Water use
	Nutrients and pollutants	Nitrogen balance
		Pesticide risk

Thus it is a measure of the farm contribution to economic wealth. It may also be viewed as a complement of farm profit in measuring economic sustainability, as it represents the amount of income produced that can be shared in different ways among the actors of the production process. When different components of the GDP (e.g. wages, interest, rent) are to be attributed to the same people, it is possible that farming systems produce acceptable (sustainable) income even with negative profits.

Farm employment provides a measure of the social implications of agriculture in terms of provision of jobs and distribution of income. In this study it is defined as the total amount of labour required by the farm.

The biodiversity indicator is quantified as the number of species cultivated on the farm.

Water use is intended as the required amount of irrigation water measured at the farm gate. Water use as a function of water price can be seen as the demand of the farm for water.

Nitrogen balance (N) is the physical difference (surplus/deficit) between nitrogen inputs and outputs at the farm gate:

$$N = \sum_i \sum_h x_i s_{ih} c_h - \sum_i \sum_z x_i y_{iz} d_z$$

where x_i is the area of crop i, s_{ih} is the amount of input h per hectare of crop i, c_h is the amount of nitrogen per unit of input h, y_{iz} is the amount of output z produced by crop i, d_z is the amount of nitrogen per unit of output z.

All anthropic nitrogen brought to the soil is considered to be input, while the harvested production is considered as output. This indicator is a better approximation with respect to the simple amount of nitrogen fertilisers used. However, it does not cover all aspects of nitrogen pollution, as it excludes natural fixation (including that produced by legumes) and mineralisation. This form of the nitrogen indicator was chosen as it represents a good compromise between mathematical tractability within economic models and sufficient proximity to real pollution mechanisms. The indicator allows for positive as well as negative values of the surplus and approximates the amount of nitrogen that, over one year, is released into the environment (air, soil, water).

The pesticides risk indicator (P) takes the same form as the nitrogen balance, considering the output to be equal to zero:

$$P = \sum_i \sum_h x_i s_{ih} c_h.$$

The value of c_h is calculated as follows:

$$c_h = \sum_t g_{ht} \frac{1,000,000}{\mathrm{LD50}_t}$$

where g_{ht} is the amount of active matter t by unit of input h and $\mathrm{LD50}_t$ (lethal dose 50) is a commonly used indicator of toxicity, given by the milligrams of active matter t necessary to kill 50% of a population of 1 kg of rats. The c_h values represents the

Table 6
Weights of different farm typologies in the different scenarios

	Model	Agenda 2000	Forecasted weight			
			World market	Global sustainability	Provincial agriculture	Local community
Cereal	1	1.000	1.000	1.000	1.000	1.000
Rice	1	0.528	0.198	0.340	0.387	0.481
	2	0.472	0.802	0.660	0.613	0.519
Fruit	1	0.307	0.285	0.300	0.300	0.307
	2	0.308	0.216	0.277	0.277	0.308
	3	0.322	0.418	0.354	0.354	0.322
	4	0.063	0.081	0.069	0.069	0.063
Vegetables	1	0.502	0.253	0.452	0.452	0.502
	2	0.498	0.747	0.548	0.548	0.498
Citrus	1	0.575	0.362	0.532	0.532	0.575
	2	0.425	0.638	0.468	0.468	0.425

weight (in kilograms) of the population of rats, 50% of which would be killed by 1 kg of the input.

3.7. Aggregation of the results for each farming system

Finally, aggregation of the results across farm types of the same farming system was carried out.

Aggregation was computed as the weighted sum of the results of each farm type in each farming system. Each farm type was weighted according to the share of usable agricultural area belonging to that farm type. However, the weighting factor may be expected to change over time, according to the scenario. For this reason, as part of the scenario analysis, a change in the proportion of each farm type in each farming system has been hypothesised (Table 6). The rationale behind such changes is that the expected increase of farm size would affect mainly the large farms, which would take over the land managed by the small ones.

The models were developed using GAMS as the optimisation software.

4. Results

4.1. Cereal – Lombardy

All scenarios yielded economic and social results that are worse than *agenda 2000*, with *world market* and *global sustainability* yielding the worst performances (Table 7).

At the same time, all scenarios show decreases in water use, with the greatest reduction (71%) in the case of *global sustainability*. This area used to be relatively

Table 7
Cereal system: impact indicators by scenario and different water prices

Water price, €	Scenario	Economic balance		Social impact	Biodiversity	Water use	Nitrogen and pollutants	
		Profit, €/ha	Farm contribution to GDP, €/ha	Farm employment, h/ha	Genetic diversity index	Water use, m^3/ha	Nitrogen balance, kg/ha	Pesticide risk index
Actual price (0.12)	A2000	91	1052	43	6	834	−30	4757
	WM	−176	504	25	5	490	−34	4797
	GS	−136	686	26	5	251	−27	4241
	PA	26	871	29	6	557	−33	4789
	LC	−84	958	31	6	618	−33	4787
Double price (0.24)	A2000	14	904	35	6	168	−32	4776
	WM	−191	468	22	5	168	−15	4224
	GS	−155	648	24	4	222	−55	4136
	PA	8	828	26	6	219	−8	4318
	LC	−116	895	29	4	231	−6	4261

rich in water, but water saving is becoming a crucial issue. In particular, it can help to guarantee availability during key periods (summer) for the most profitable crops (e.g. melons and water melons). Nitrogen and pesticide indicators are basically stable across scenarios.

The impact of water pricing appears to be very important only for water use and, to a lesser extent, for nitrogen use indicators. Doubling the price will lead to falls of up to 70% in water use, with greater effects on those scenarios that use more water at the present prices. A further increase shows basically no relevant effects. The impact on profit appears to be negligible.

4.2. Rice – Emilia romagna

As in the previous case, economic results are always worse than in *agenda 2000*, the worst scenario being by far *world market* (Table 8).

In this case, profit and GDP are so low as to make the cultivation of this particular area no longer profitable. Due to the agronomic constraints of the area, it is not possible to change the crop mix and, when rice cultivation is no longer profitable, then farmland may be gradually abandoned or part of the area may be reconverted to wetlands. Such results are associated with a major reduction in water (connected to a decrease in rice cultivation) and nitrogen use, while pesticide use shows some increase. An important reduction in the use of labour also occurs in this scenario.

Water price has a relevant impact on profit as well as on water use in all scenarios, with the partial exception of *global sustainability*. Note that the relative increase in water price is, in fact, very low in absolute terms, denoting an insignificant sensibility of the system to this parameter.

4.3. Fruit – Emilia romagna

The system is basically stable and able to match most of the scenarios without any major changes in the crop mix and in the value of indicators (Table 9).

The more significant changes concern profitability and the contribution to GDP resulting from changes in the price system across scenarios. The fruit system is mostly based on family farms, where net income incorporates most of the components of the GDP. For this reason, the system may be considered sustainable, even with negative profit (if farmers accept a certain degree of under-remuneration of family labour, as they do at present), as long as the contribution to GDP appears high and relatively stable across scenarios.

Environmental impact is strong, and remains relatively stable across scenarios. *Local community*, putting higher emphasis on local, high quality fruit production, tends to increase fruit cultivation, with higher GDP associated with an increase in the impact from pesticides.

Water usage is already highly efficient, as it is based mainly on drip irrigation, and all scenarios are characterised by a slight further reduction in water use. However, the amount of water used does not change significantly, with shifts across scenarios of around ±15% and a decrease on average of around 10% when the price doubles.

Table 8
Rice system: impact indicators by scenario and different water prices

Water price, €	Scenario	Economic balance		Social impact	Biodiversity	Water use	Nitrogen and pollutants	
		Profit, €/ha	Farm contribution to GDP, €/ha	Farm employment, h/ha	Genetic diversity index	Water use, m^3/ha	Nitrogen balance, kg/ha	Pesticide risk index
Actual price (0.016)	A2000	−19	1090	27	4.47	7435	−42	493
	WM	−611	394	13	3.20	2144	−88	657
	GS	−295	849	20	5.00	4130	−75	304
	PA	−73	1057	23	4.61	6018	−61	470
	LC	−87	1100	23	4.52	6097	−32	432
Double price (0.032)	A2000	−126	958	22	3.53	5593	−71	658
	WM	−634	285	8	3.20	814	−23	617
	GS	−362	782	20	5.00	4072	−74	307
	PA	−170	961	23	4.61	6018	−61	470
	LC	−180	989	21	4.00	4354	−35	495

Table 9
Fruits system: impact indicators by scenario and different water prices

Water price, €	Scenario	Economic balance		Social impact	Biodiversity	Water use	Nitrogen and pollutants	
		Profit, €/ha	Farm contribution to GDP, €/ha	Farm employment, h/ha	Genetic diversity index	Water use, m^3/ha	Nitrogen balance, kg/ha	Pesticide risk index
Actual price (0.15)	A2000	−297	3084	239	8.95	1287	67	30995
	WM	−861	2107	186	8.25	993	65	22887
	GS	−963	2709	214	7.25	1045	64	24108
	PA	−657	2704	212	8.32	1028	67	25999
	LC	−651	3644	233	9.57	1116	67	32966
Double price (0.30)	A2000	−455	2877	236	8.89	1031	67	30737
	WM	−992	1953	185	8.25	901	65	23004
	GS	−1108	2540	214	6.94	948	64	23131
	PA	−807	2537	212	8.32	937	67	25998
	LC	−809	3384	229	9.57	1062	67	32276

4.4. Vegetables – Apulia

Analogous to the previous case, contribution to GDP is relatively stable across scenarios, while profit shows major changes, with *local community* yielding the worst results (Table 10).

However, *global sustainability* would allow an increase in both GDP and profits. While in *local community* the low economic results appear to be associated with lower water and pesticide use, such a relationship is not so clear for the other scenarios. In particular, *world market* and, to some extent, *provincial agriculture*, predict lower incomes associated with higher water, nitrogen and pesticide use, due to a reduction in the relative profitability of rain-fed crops (durum wheat). Labour and biodiversity are basically stable across scenarios.

Compared with the differences among scenarios, the impact of water price is moderate, both in terms of economic results and environmental impact, with the exception of relative changes in farm profit. Only *local community* and, to a lesser extent, *agenda 2000* and *provincial agriculture* scenarios show relevant changes in water use and environmental effects when the price increases.

4.5. Citrus fruit – Sicily

All the scenarios show the structural weakness of this agricultural system, with a strong reduction (up to 80% in *provincial agriculture*) in GDP (Table 11).

Profits are negative due to the labour-intensive nature of this kind of farming, which is analogous to the fruit system. However, in the case of citrus, the effects of negative scenarios tend to lead to a substitution of cereals for citrus. This is the reason why profits may increase, while GDP and labour decrease strongly. In reality, such changes would be attenuated by the time taken for adaptation and by resistance to the abandonment of traditional citrus cultivation. The system may be expected to continue producing citrus fruit, with no relevant changes compared with the present situation, even if profits are strongly negative and water consumption very high. When citrus cultivation is no longer sustainable (i.e. under-remuneration of farm labour is no longer acceptable), oranges may be replaced by a rain-fed crop mix based on durum wheat and minor crops. Important reductions in water use, nitrogen pollution and pesticides use are associated with reduction of citrus farming and, hence, with worse economic results.

The impact of increased water prices appears always relevant, due to the fact that the cost of water at the farm is already extremely high. Consequences include a fall in profits, GDP and labour use, as well as a reduction in irrigation and a strong reduction in pollution. Such effects occur at lower prices for the other scenarios, where the effect of the water price would be added to that of agricultural markets and policy. In the case of *local community*, even the present price of water makes citrus cultivation unsustainable.

Table 10
Vegetables system: impact indicators by scenario and different water prices

Water price, €	Scenario	Economic balance		Social impact	Biodiversity	Water use	Nitrogen and pollutants	
		Profit, €/ha	Farm contribution to GDP, €/ha	Farm employment, h/ha	Genetic diversity index	Water use, m^3/ha	Nitrogen balance, kg/ha	Pesticide risk index
Actual price (0.09)	A2000	467	2580	91	2.50	2185	72	95518
	WM	151	2459	100	3.49	2495	91	112756
	GS	622	2989	92	3.10	2146	74	71084
	PA	392	2620	92	3.10	2253	78	111536
	LC	−13	2310	89	3.00	1895	63	57610
Double price (0.18)	*A*2000	269	2383	91	2.50	2185	72	95518
	WM	−76	2235	100	3.49	2495	91	112756
	GS	427	2796	92	3.10	2146	74	71084
	PA	178	2381	91	3.10	2121	72	100324
	LC	−186	2040	80	3.00	1767	61	53947

Table 11
Citrus system: impact indicators by scenario and different water prices

Water price, €	Scenario	Economic balance		Social impact	Biodiversity	Water use	Nitrogen and pollutants	
		Profit, €/ha	Farm contribution to GDP, €/ha	Farm employment, h/ha	Genetic diversity index	Water use, m^3/ha	Nitrogen balance, kg/ha	Pesticide risk index
Actual price (0.31)	A2000	−1827	3410	532	1.00	4733	174	48725
	WM	−1815	1611	268	2.00	2648	110	42170
	GS	−763	1611	78	1.47	1076	50	26760
	PA	−2503	857	449	1.47	3739	137	40379
	LC	−550	2507	1	1.00	0	8	13495
Double price (0.62)	A2000	−645	632	78	1.43	1130	52	38228
	WM	−735	632	1	1.00	0	10	22838
	GS	−526	−313	1	1.00	0	9	14533
	PA	−547	−117	1	1.00	0	9	22838
	LC	−550	−137	1	1.00	0	8	13495

5. Discussion

The results show the varied reactions of Italian irrigated farming systems faced with possible agricultural and water policy scenarios. In most cases, the process of liberalisation assumed under the *world market* scenario would yield the worst results in terms of economic sustainability, while inducing a reduction in environmental impact as measured by water use, nitrogen pollution and pesticide use. In this case, a reduction in water consumption may be sufficient to meet WFD objectives even without the need for strict pricing policies. Other scenarios show more diverse outcomes, but generally yield worse economic and social results than *agenda 2000*.

Water pricing will have, in most cases, lower effects than agricultural markets and policy scenarios. As far as water use is concerned, only the cereal, rice and citrus systems show important reactions to water prices, often in those scenarios that already yield a lower income.

Reduced environmental impact, with few exceptions, is associated with unsatisfactory economic outcomes, showing a clear trade-off between reducing negative impacts from agriculture and maintaining the livelihood of the sector. Also, caution should be placed on interpreting the indicators produced in this study as fully representing sustainability. In most cases, the reduction of water and chemicals use derived from unfavourable economic conditions would mainly translate to land abandonment and reduced biodiversity, effects which are not dominated by the model. A clear example is citrus farming, where reduction in water and pesticide use is basically obtained by inducing the abandonment of citrus farming, often without relevant substitutes.

The main policy implications concern water regulation for irrigation. First of all, particularly if the less sustainable scenarios prevail, an increase in water price should be proposed carefully as it could lead to an excessive burden, making the sector economically unsustainable. On the other hand, only annual non-intensive crop systems (rice systems and, especially, cereal systems) would react sufficiently to water pricing to justify its use as an incentive to water saving. In other cases, where the water demand curve is less reactive to price increases, pricing could play mostly the role of satisfying FCR, unless prices become so high that they lead to the abandonment of the main crops.

Altogether, it is clear that any policy aimed at water saving and economic efficiency needs to take into account possible agricultural scenarios and their effects on water use. More importantly, there appears to be a need for a common policy design framework, at least at the local level, if undesired economic, social and environmental effects from the implementation of the WFD are to be avoided.

The present study highlights the need for a broader view in terms of integrated analysis with other water uses. It also suggests further research into water policy design, beyond volumetric pricing, taking into account various different policy instruments, information structures and innovative forms of water management, such as water markets. Explicit consideration of transaction costs connected with different policy instruments would bring the analysis even closer to reality. The study results also call for greater attention to the joint regulation of water quantity use and water quality associated with fertiliser and pesticide use.

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