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Projections of economic impacts of climate change in agriculture in Europe

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SUMMARY: This study provides monetary estimates of the impacts of climate change in European agriculture. Future scenarios are derived from several socio-economic scenarios and experiments conducted using global climate models and regional climate models. The economic valuation is conducted by using GTAP general equilibrium model across simulations based on crop productivity changes that consider no restrictions in the volume of water available for irrigation in current irrigated areas or in the application of nitrogen fertilizer. Thus the results should be considered optimistic from the production point and pessimistic from the environmental point of view. Regional differences between northern and southern European countries are found and the monetary estimates show that uncertainty derived from socio-economic scenarios has a larger effect than uncertainty derived from climate scenarios.

KEY WORDS: Agriculture, climate change, general equilibrium models.

JEL classification: Q54, D58, Q11.

Proyecciones del impacto económico del cambio climático sobre la agricultura en Europa

RESUMEN: Este estudio proporciona estimaciones económicas de los efectos del cambio climático en la agricultura Europea. Los escenarios futuros incorporan proyecciones de cambios socio-económicos y variables climáticas derivadas de modelos de clima global y regional. La valoración económica utiliza el modelo de equilibrio general GTAP, donde las simulaciones se basan en cambios en la productividad de los cultivos sin considerar restricciones en el volumen de agua de riego en las zonas actuales de regadío ni de fertilizantes. Así, los resultados se pueden considerar optimistas desde el punto de vista productivo pero pesimistas desde el punto de vista medio ambiental. Se observan diferencias regionales significativas entre el norte y sur de Europa y las estimaciones económicas muestran que la incertidumbre asociada a los escenarios socio-económicos es mayor que la asociada a los escenarios climáticos.

PALABRAS CLAVE: Agricultura, cambio climático, modelos de equilibrio general.

Clasificación JEL: Q54, D58, Q11.

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1. Introduction

Agriculture in the European Union faces some serious challenges in the coming decades: competition for water resources, rising costs due to environmental protection policies, competition for international markets, loss of comparative advantage in relation to international growers, climate change and the uncertain in effect of the current European policies as adaptation strategies. Demographic changes are altering vulnerability to water shortages and agricultural production in many areas, with potentially serious consequences at local and regional levels. Population and land-use dynamics, and the overall policies for environmental protection, agriculture, and water resources management, determine, and limit, possible adaptation options to climate change. An improved understanding of the climate-agriculture-societal response interactions is highly relevant to European policy.

According to the IPCC Fourth Assessment Report (IPCC, 2007), climate change is already happening, and will continue to happen even if global greenhouse gas emissions are curtailed. There is now concern that global warming has the potential for affecting the climatic regimes of entire regions (IPCC, 2007). Many studies document the implications of climate change for agriculture, and show that these effects vary between different regions and different scales (global, regional and local) (IPCC, 2007; Olesen and Bindi, 2002; Iglesias and Quiroga, 2007). These resulting effects depend on the complex relationships between climate change and agriculture that involve climatic and environmental aspects (physical effects) and social and economic responses. At the global level, the economic implication of changes in agricultural production highlights the vulnerability of food security (Gregory *et al.,* 2005; Parry *et al.*, 1999, 2001, 2004), posing a reasonable concern that climate change is a threat to poverty and sustainable development, especially in marginal areas.

Several types of economic approaches have been used for agricultural impact assessment in order to estimate the potential impacts of climate change on production, consumption, income, gross domestic product (GDP), employment, and farm value (Darwin, 2004; Kaiser *et al.*, 1993; Reilly *et al.,* 2003). Microeconomic models based on the goal of maximizing economic returns to inputs have been used extensively in the context of climate change (Antle and Capalbo, 2001). They are designed to simulate the decision-making process of a representative farmer regarding methods of production and allocation of land, labour, existing infrastructure, and new capital. These farm models have most often been developed as tools for rural planning and agricultural extension, simulating the effects of changes in inputs (e.g., fertilizers, irrigation, credit, management skills) on farm strategy (e.g., cropping mix, employment). The effects of climate change in regional, national, or global agricultural economy are analysed by using macroeconomic models. For climate change purposes, the models allocate domestic and foreign consumption and regional production based on given perturbations of crop production, water supply, and demand for irrigation derived from biophysical techniques. Population growth and improvements in technology are set exogenously. These models measure the potential magnitude of climate change impacts on the economic welfare of both producers and consumers of agricultural goods. The predicted changes in production and prices from agricultural sector models can then be used in general equilibrium models of the larger economy. All studies have considered adaptation aspects explicitly to some degree, but some studies consider adaptation implicitly by using the Ricardian approach (Mendelsohn *et al*., 1999; 2004).

Computable General Equilibrium (CGE) models comprise a representation of all major economic sectors, empirically estimated parameters and no unaccounted supply sources or demand sinks (Conrad, 2001). In general equilibrium models countries are linked through trade, world market prices and financial flows, and change in relative prices induce general equilibrium effects throughout the whole economy. Although partial equilibrium models make it possible to estimate the costs of policy measures, taking substitution processes in production and consumption as well as market clearing conditions into account, CGE models additionally allow for adjustments in all sectors, enable to consider the interactions between the intermediate input market and markets for other commodities or intermediate inputs, and complete the link between factor incomes and consumer expenditures. General equilibrium models have been used as tools to make monetary estimations of the consequences of climate change in the agricultural sector (Tsigas *et al*., 1997; Bosello and Zang, 2005; Kane *et al*., 1992; Parry *et al.,* 1999, 2003, 2004).

The objective of this study is to provide monetary estimates of the impacts of climate change in European agricultural sector. The future scenarios incorporate a range of socio-economic projections and experiments conducted using global climate models and regional climate models (Iglesias *et al.,* 2007a; European Commission, 2007). The quantitative results are based on numerical models and exposure-responses functions formulated considering endogenous adaptation within the rules of the modelling framework. The results include production potential, production value and trade variations in the future for a range of climate scenarios in different agricultural regions under different policy considerations. Water restrictions and socio-economic variables that modify the probabilities of change occurring may also be considered in a later stage of the study.

2. Methods and data

2.1. *Approach*

The response of crop production to climate change is driven by changes in crop yields as this strongly influences farmer decisions about profitability. Crop yields respond to climate change through the direct effects of weather, atmospheric CO_2 concentrations, and water availability. Several hundred studies have now been completed on the impacts and adaptation of climate change on agriculture, and these can provide examples both of the types and magnitude of climate change likely to be most important (a recent complete summary is included in the IPCC, 2007). Agronomic implications of climate change in agriculture include in the first place the direct effect of atmospheric CO_2 concentration in biomass production and evapotranspiration (Tubiello and Ewert, 2002; Long *et al.,* 2006). Second, the results depend on the effects of changes in the climate variables in the time of production (Olesen and Bindi, 2002,), optimal management options (Porter and Semenov, 2005), weeds, pests and diseases (Iglesias and Rosenzweig, 2002; Salinari *et al.,* 2006), water demand (Arnell, 2004; Iglesias *et al.,* 2007b), and direct effects in soil fertility (Rounsewell *et al.,* 2005. Finally, changes in climate variability and the intensity and frequency of extreme events may be the main determinants of agricultural production (Rosenzweig *et al.,* 2002). Although different methods of impact assessment may be used depending on the objective of the study, agronomic studies can best be achieved through use of process-based crop growth models that link climate, management and environmental variables to crop production. Effects on income, livelihoods, and employment can only be assessed using economic and social forms of analysis (Reilly *et al*., 2003). An advantage of using GE models for this type of analysis is that the linkages between population increase and food production can be explored (Hertel, 1997; Conrrad, 2001).

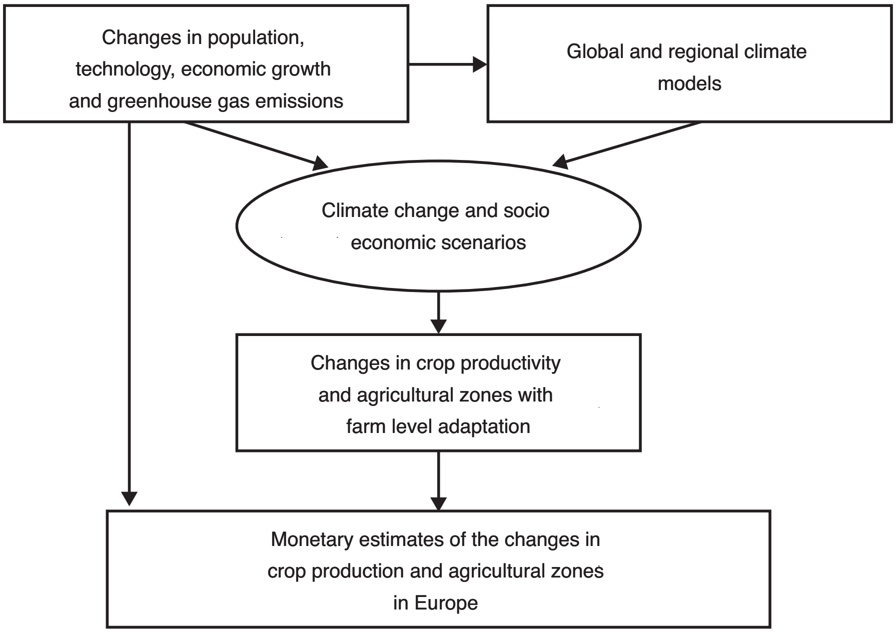
Iglesias *et al*. (2000, 2007a) estimated crop production functions at the regional level taking into account water supply and demand, social vulnerability and adaptive capacity; therefore the functional forms take into account from the onset adaptation at the agricultural level. Adaptation at the policy level is reflected by the choice of the socio-economic scenario in each case (see below). The functional forms for each region represent the realistic water limited and potential conditions for the mix of crops, management alternatives, and endogenous adaptation to climate characteristic of each area. Here we take the changes in crop under several climate and socio-economic scenarios and use them as inputs for the monetary evaluation (Figure 1). Future climate change scenarios are driven by changes in socioeconomic variables (i.e., population, technology, economic development, etc) that result in different greenhouse gas emissions (i.e., CO_2 and other gases). These changes are then used as inputs to global climate models to project changes in climate conditions. The scenarios considered in this study were developed for the PESETA project (PESETA, http://peseta.jrc.es/index.htm) and included in the European Commission Green Paper on adaptation to climate change (European Commission, 2007). Similar approaches have been proven valuable when estimating the food security and agricultural trade consequences of climate change (Parry *et al*., 1999; 2001; 2004).

2.2. *Changes in crop production*

Changes in crop production were estimated at the regional and country level based in the Europe-wide spatial changes in crop production and agricultural zones provided by Iglesias *et al*. (2007a). Adaptation was explicitly considered and incorporated into the results by assessing country or region's potential for reaching optimal crop yield. Optimal yield is the potential yield given non-limiting water applications in the current irrigated areas, fertilizer inputs, and management constraints. It is im-

FIGURE 1

Summary of the approach



Source: Own elaboration.

portant to notice that no further irrigated areas are considered. The consideration of non-limited volume of water application in the current areas may be an overestimation of the adaptive capacity of the agricultural sector. Nevertheless, a scenario with reduction in the volume of water is not available over the wide geographical area covered in the study. Adapted yields are evaluated in each country or region as a fraction of the potential yield. The weighting factor combines the ratio of current yields to current yield potential and current growth rates in crop yields and agricultural production.

2.3. *Socio-economic scenarios for policy analysis*

Main primary driving forces for the socio-economic scenarios considered are in Table 1, and the storylines of the scenarios (IPCC SRES, 2001; Arnell *et al.*, 2004) are explained bellow. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines. Some of the implications of this scenario are: lower levels of wealth and regional disparities; stress and damage of natural systems at the local and global levels; mixed coping capacity but decreased in areas with lower economic growth; and overall increase in vulnerability.

In contrast, the B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. Some of the implications of this scenario are: lower levels of wealth and regional disparities; environmental protection is a priority, although strategies to address global problems are less successful than in other scenarios, meaning that the ecosystems will be under less stress than in the rapid growth scenarios; the coping capacity is improved at the local level; and the vulnerability is derived from a global environmental stress but local resiliency.

TABLE 1

Overview of main primary driving forces in 1990, 2050, and 2100 for the A2 and B2 scenarios

Scenario group	A2	B2
Population (billion) (1990 = 5.3)		
2050	11.3	9.3
2100	15.1	10.4
World GDP (10^{12} 1990 US$/ yr) (1990 = 21)		
2050	82	110
2100	243	235
Per capita income ratio: developed countries and economies in transition (Annex - I) to developed countries (Non-Annex-I) (1990 = 16.1)		
2050	6.6	4.0
2100	4.2	3.0

Source: Adapted from the Special Report on Emission Scenarios, IPCC SRES, 2001.

2.4. *Climate change scenarios*

Five climate scenarios were used in the study (Table 2), constructed as a combination of Global Climate Models (Had CM2 and ECHAM4) downscaled for Europe with the HIRHAM and RCA3 regional models and driven by the SRES A2 and B2 socio-economic scenarios (Table 1). The scenarios were derived from the data provided by the PRUDENCE project (PRUDENCE, 2006).

TABLE 2

Summary of the five climate scenarios used in the study

Scenario	Time frame	Driving Socio-economic scenario SRES	Driving Global climate models (GCM)	Regional climate models	Average CO_2 ppmv	Change in average annual temperature in Europe (ºC)
HadCM3 A2 / DMI/HIRHAM 2080s **(Scen 1)**	2071-2100	A2	HadCM3	DMI/HIRHAM	709	3.1
HadCM3 B2 / DMI/HIRHAM 2080s **(Scen 2)**	2071-2100	B2	HadCM3	DMI/HIRHAM	561	2.7
ECHAM4/OPYC3 A2 / SMHI/RCA3 2080s **(Scen 3)**	2071-2100	A2	ECHAM4	SMHI/RCA3	709	3.9
ECHAM4/OPYC3 B2 / SMHI/RCA3 2080s **(Scen 4)**	2071-2100	B2	ECHAM4	SMHI/RCA3	561	3.3
ECHAM4/OPYC3 A2 / SMHI/RCA3 2020s **(Scen 5)**	2011-2040	A2	ECHAM4	SMHI/RCA3	424	1.9

Source: PESETA Project, http://peseta.jrc.es/index.htm).

2.5. *General equilibrium model*

For the CGE simulation we use the GTAP general equilibrium model system (Hertel, 1997) calibrated in 2001 (GTAP 6 database), which is the global data base representing the world economy for 2001 year. Dimaranan and McDougall (2006) expose the regional, sector and factors aggregation of the data base.

The general equilibrium approach of GTAP includes broadly all relevant economic activities. Financial flows as well as commodity flows at the international level are consistent in the sense that they balance. The countries are linked through trade, world market prices and financial flows. The system is solved in annual increments, simultaneously for all countries. It is assumed that supply does not adjust instantaneously to new economic conditions. Only supply that will be marketed in the following year is affected by possible changes in the economic environment. A first round of exports from all the countries is calculated for an initial set of world prices, and international market clearance is checked for each commodity. World prices are then revised, using an optimising algorithm, and again transmitted to the national models. Next, these generate new domestic equilibrium and adjust net exports. This process is repeated until the world markets are cleared in all commodities. Since these steps are taken on a year-by-year basis, a recursive dynamic simulation results.

In our simulation, the model aggregation considers 16 regions, 3 sectors and 4 factors. The 87 GTAP regions were mapped to 16 new regions that are Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and a macro region integrating the rest of 87 GTAP regions, called Rest of World (ROW). The 57 GTAP sectors were aggregated into 3 new sectors which detailed components are in Table 3. The factors considered are Land, Labour (including unskilled and skilled labour), Capital and Natural Resources (Energy).

TABLE 3

Summary of the sectors included in the GTAP model

Crops	Paddy rice, wheat, cereal grains, processed rise, vegetables, fruits and nuts, oil seeds, sugar cane and sugar beet, plant based fibres, crop mix, vegetable oils and facts and sugar.
Other agrarian goods	Wool, silk-worm cocoons, meat: cattle, sheep, goats and horse, meat products, food products, beverages and tobacco.
Manufactures and Services	Rest of 57 GTAP sectors.

Source: Own elaboration.

Following Bosello and Zhang (2005), we first pseudo-calibrate the model, deriving a baseline equilibrium «without climate change». A pseudo-calibration is a simulation that includes changes in population and technology but not in climate variables. This is an essential representation of the future without climate change. For this purpose, we used population increase and technological change as key variables for the baseline projections. In the second step, we evaluate the climate change physical impacts on agriculture, using the GTAP general equilibrium model (Hertel, 1997) calibrated in 2001. For the Baseline, the increase in population was considered from the IMAGE model considering the most adaptive scenario B1 (IPCC SRES, 2001).

As it is revised on Grubb et al. (2002), there is no consensus on the technological change modelling. Macroeconomic environmental models such as GREEN, GEM-E3 and G-cubed have a constant autonomous energy efficiency improvement, typically in a range of 0.5-2.5% a year, while the DICE model has an exponential slowdown in productivity growth ($1-e^{dt}$) starting from a base of 1.41% per year in 1965 with the constant d set at 0.11 per decade. In our model, we first use the DICE approach for technological change modelling, starting from the base of 1% per year in 2001 and the same constant d per decade. But then, we used the G-cubed constant value for robustness testing.

For the second step, we implement the physical impacts on agriculture calculated using agricultural models as calculated in previous studies (Iglesias *et al.,* 2000; 2007a; Parry *et al.,* 1999; 2001; 2004). The physical impacts on agriculture (Table 4) were estimated at the grid level and aggregated over agroclimatic areas (Iglesias et al., 2007a and http://peseta.jrc.es/index.htm for further information and the complete report on physical impacts), so to integrate it at the GTAP model it has been necessary to aggregate into country level taking into account the agroclimatic areas in each European country.

TABLE 4

Average regional changes in crop yield and coefficient of variation under the climate change scenarios (full description in Table 2) compared to baseline

Country	HadCM3/ HIRHAM A2 2080 (Scen 1)		HadCM3/ HIRHAM B2 2080 (Scen 2)		ECHAM4/RCA3 A2 2080 (Scen 3)		ECHAM4/RCA3 B2 2080 (Scen 4)		ECHAM4/RCA3 A2 2030 (Scen 5)	
Region	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %
Boreal	41	38	34	32	54	22	47	15	77	44
Continental North	1	2	4	2	–8	7	1	4	7	5
Continental South	26	17	11	19	33	30	24	6	17	29
Atlantic North	–5	6	3	6	22	17	16	10	24	15
Atlantic Central	5	24	6	27	19	38	17	23	32	30
Atlantic South	–10	5	–7	3	–26	10	–12	9	9	20
Alpine	21	14	23	17	20	24	20	20	–13	49
Mediterranean North	–8	4	0	3	–22	8	–11	7	–2	13
Mediterranean South	–12	41	1	43	–27	41	5	46	28	83

Source: Iglesias *et al*., 2007a.

The productivity shock has been introduced in GTAP as land-productivity- augmenting technical change over crop sector in each region. We also include the increase in population projected for each considered scenario (A2 and B2) IPCC SRES (2001) listed on Table 5. The OECD values have been used for the European countries and the World values for the rest of the world (ROW).

TABLE 5

Population increases with respect 2001 for B1, A2 and B2 scenarios (%)

	SRES B1		SRES A2		SRES B2
	2030	**2080**	**2030**	**2080**	**2080**
OECD	16.6	20.1	22.5	43.3	2.7
World	39.6	33.0	73.7	124.1	66.8

Source: OCDE.

3. Results

3.1. *Spatial effects*

The physical impacts on agriculture aggregated into country level are in Table 6. The yield changes include the direct positive effects of CO_2 on the crops, the rain-fed and irrigated simulations in each district. Table 6 summarises the average country changes in crop yield under the HadCM3/HIRHAM A2 and B2 scenarios for the 2080s and for the ECHAM4/ RCA3 A2 and B2 scenarios for the 2030s compared to baseline. The results are in agreement with the biophysical processes simulated with the calibrated crop models, agree with the evidence of previous studies, and therefore have a high confidence level (Olesen and Bindi, 2002; Iglesias *et al*., 2000; Parry *et al*., 1999; 2001; 2004). In general, northern countries increase agricultural productivity under all scenarios while Mediterranean countries decrease productivity. In some regions, such as the Alpine region, future agriculture has a large degree of uncertainty, since the results depend highly on the selected climate and socio-economic scenario (Table 6).

TABLE 6

Average % changes by country in crop yield under climate change scenarios (full description in Table 2) compared to baseline

Country	HadCM3/ HIRHAM A2 2080 (Scen 1)	HadCM3/ HIRHAM B2 2080 (Scen 2)	ECHAM4/RCA3 A2 2080 (Scen 3)	ECHAM4/RCA3 B2 2080 (Scen 4)	ECHAM4/RCA3 A2 2030 (Scen 5)
Austria	18.4	20.5	16.7	17.9	–10.6
Belgium	5.3	6.5	18.7	17.2	32.0
Denmark	5.3	6.5	18.7	17.2	32.0
Finland	24.5	21.4	37.8	33.4	56.3
France	–2.4	2.5	–6.1	2.6	15.0
Germany	3.4	5.7	1.7	7.1	14.3
Greece	–12.0	1.0	–27.4	5.5	27.8
Ireland	–5.0	2.8	22.1	16.1	24.5
Italy	–8.0	2.0	–21.8	–0.6	12.3
The Netherlands	5.3	6.5	18.7	17.2	32.0
Portugal	–10.6	–4.0	–26.6	–5.6	16.0
Spain	–11.0	–0.1	–26.2	0.1	19.7
Sweden	23.2	20.4	36.4	32.3	54.5
Switzerland	20.8	22.8	20.2	20.3	–13.1
United Kingdom	1.5	5.2	20.0	16.8	29.3

Source: Own elaboration.

3.2. *Economic effects of climate change*

The crop functions have been used to derive monetary impacts of climate change in the entire European agricultural sector by using GTAP model that considers the production, consumption, and policy. Figures 2 and 3 show the estimated changes in the exports and imports of crops and other agricultural under the climate and socio-economic scenarios with respect to the baseline. Changes in Value of GDP and changes in Value of World Supply are in Table 7, and Table 9 respectively. Following the changes in crop productivity, trade changes are, in general, larger in northern European countries. Relatively small changes in traditionally agricultural Mediterranean countries may imply that current agricultural systems in these countries need to be re-evaluated. Table 8 shows the small differences in the GDP changes when using the G-cubed constant value instead of DICE model for robustness testing.

TABLE 7

% Change in Value of GDP under climate change scenarios (full description in Table 2) compared to baseline

Country	HadCM3/HIR-HAM A2 2080 (Scen 1)	HadCM3/HIR-HAM B2 2080 (Scen 2)	ECHAM4/RCA 3 A2 2080 (Scen 3)	ECHAM4/RCA 3 B2 2080 (Scen 4)	ECHAM4/RCA 3 A2 2030 (Scen 5)
Austria	–0.62	–0.21	–0.63	–0.21	–0.22
Belgium	–0.60	–0.21	–0.60	–0.20	–0.20
Denmark	–0.19	–0.17	–0.17	–0.15	–0.02
Finland	–0.74	–0.24	–0.75	–0.24	–0.25
France	–0.49	–0.15	–0.50	–0.15	–0.15
Germany	–0.60	–0.20	–0.60	–0.20	–0.19
United Kingdom	–0.68	–0.17	–0.68	–0.16	–0.21
Greece	–0.46	–0.01	–0.52	0.01	–0.04
Ireland	–0.59	–0.25	–0.59	–0.25	–0.19
Italy	–0.61	–0.17	–0.64	–0.17	–0.18
Luxembourg	–0.70	–0.13	–0.69	–0.12	–0.19
The Netherlands	–0.17	–0.20	–0.14	–0.18	–0.03
Portugal	–0.62	–0.21	–0.63	–0.21	–0.20
Spain	–0.38	–0.16	–0.43	–0.16	–0.08
Sweden	–0.65	–0.21	–0.65	–0.21	–0.20
Rest of the World (ROW)	–0.04	0.02	–0.04	0.02	0.01

Source: Own elaboration.

TABLE 8

Sensitivity analysis. Differences between the Changes in Value of GDP pseudo-calibrated with DICE Model and G-Cubed constant value

Country	HadCM3/HIR-HAM A2 2080 (Scen 1)	HadCM3/HIR-HAM B2 2080 (Scen 2)	ECHAM4/RCA 3 A2 2080 (Scen 3)	ECHAM4/RCA 3 B2 2080 (Scen 4)	ECHAM4/RCA 3 A2 2030 (Scen 5)
Austria	0.003	-0.005	-0.002	0.003	-0.001
Belgium	-0.001	0.006	-0.003	0.001	-0.003
Denmark	-0.005	-0.001	-0.007	-0.001	0.004
Finland	0.005	-0.002	-0.001	0.005	0.007
France	-0.001	-0.003	0.005	0.006	-0.002
Germany	0.005	0.002	-0.001	-0.002	0.002
United Kingdom	0.002	-0.002	-0.003	0.000	-0.002
Greece	-0.005	0.000	-0.001	0.001	0.007
Ireland	0.001	0.002	-0.001	0.006	0.002
Italy	0.004	0.002	0.004	0.005	-0.003
Luxembourg	-0.004	-0.006	-0.008	-0.009	-0.001
The Netherlands	0.002	-0.003	0.002	-0.004	0.005
Portugal	-0.004	0.003	-0.003	0.002	0.001
Spain	-0.008	-0.008	-0.003	-0.008	-0.001
Sweden	0.003	0.003	-0.006	-0.003	0.004
Rest of the World (ROW)	-0.004	0.000	-0.002	-0.002	0.004

Source: Own elaboration.

TABLE 9

% Change in Value of World Supply under climate change scenarios (full description in Table 2) compared to baseline

	HadCM3/ HIRHAM A2 2080	HadCM3/ HIRHAM B2 2080	ECHAM4/ RCA3 A2 2080	ECHAM4/ RCA3 B2 2080	ECHAM4/ RCA3 A2 2030
Crops	36.43	11.61	36.50	11.58	13.14
Other Agrarian Goods	19.68	5.20	19.69	5.19	7.08
Manufactures and Services	-2.08	-0.60	-2.09	-0.59	-0.72

Source: Own elaboration.

Comparing the results in Table 7 and Table 9 across scenarios with the same climate model but different socio-economic signal, we can see that the effects on GDP and World Supply value vary to a greater amount in the case of A2 socio-economic scenarios, while the variation between the same socio-economic scenarios and different climate models are not so high.

In Figure 2 and 3, it can be observed how exports are more changeable than imports. Imports vary a lot as function of socio-economic scenario. While the European countries seem to increase the crops and other agricultural imports from the rest of the world in the A2 scenarios, the opposite effect can be sustained in the B2 scenarios.

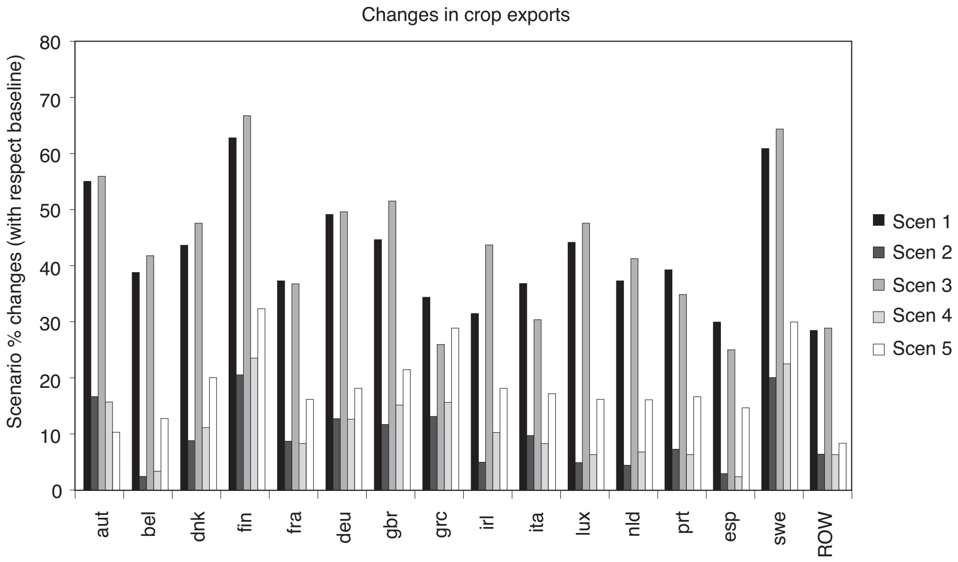
4. Discussion

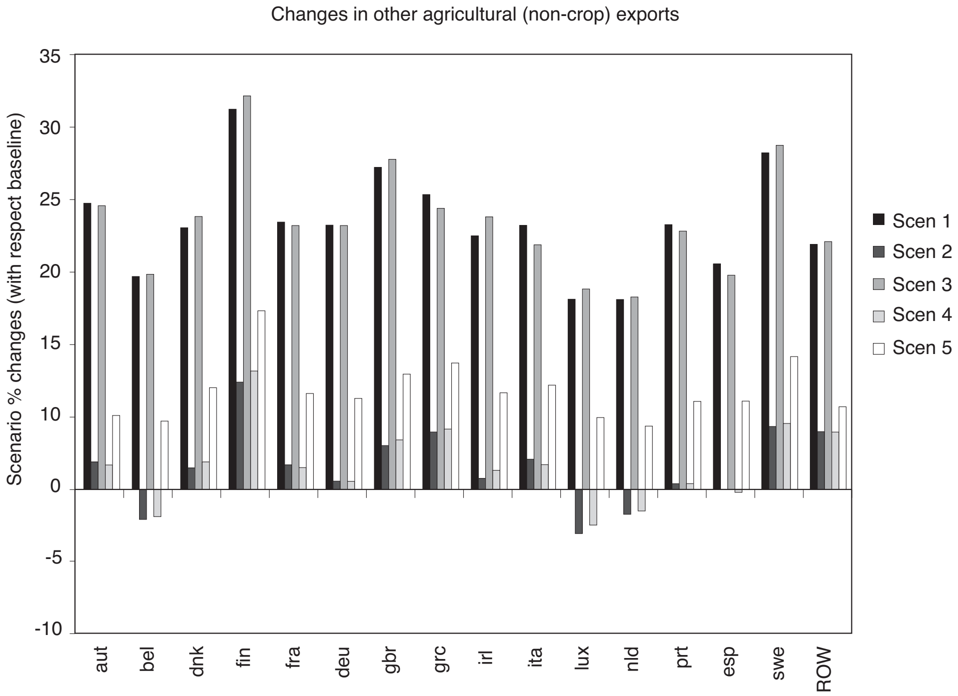
Climate change scenarios are derived from GCMs driven by changes in the atmospheric composition that in turn is derived from socio-economic scenarios. In all regions, uncertainties with respect to the magnitude of the expected changes result in uncertainties of the agricultural evaluations (Maracchi *et al*., 2004; Olesen and Bindi, 2002; Porter and Semenov, 2005; Iglesias and Quiroga, 2007). The uncertainty derived from the climate model related to the limitation of current models to represent all atmospheric processes and interactions of the climate system. The limitations for projecting socio-economic changes not only affect the SRES scenarios but also the potential adaptive capacity of the system. For example, uncertainty of the population (density, distribution, migration), gross domestic product, technology, determine and limit the potential adaptation strategies. In this study we include a range of scenarios representing upper and lower bounds of the predicted effects to decrease the uncertainty of the results.

Iglesias *et al*. (2007a) show that although each scenario projects different results, all scenarios are consistent in the spatial distribution of effects. The results are in agreement with recent European wide analysis (EEA, 2005; IPCC, 2007; Ewert *et al*., 2005; Rounsevell *et al*., 2006; Rounsevell *et al*., 2005). It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in

FIGURE 2

Estimated % changes in the exports of crops and other agricultural u under climate change scenarios (full description in Table 2) compared to baseline

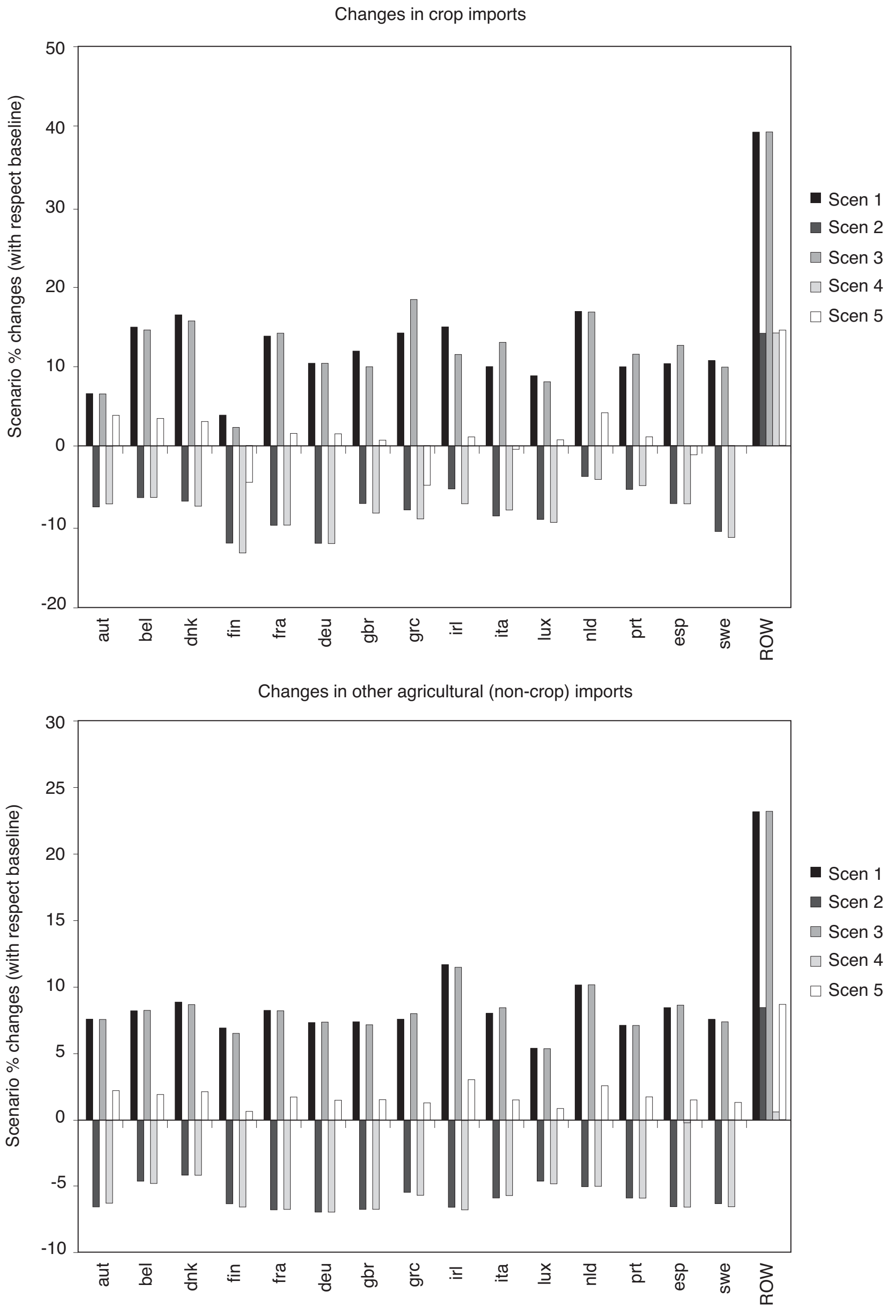




Source: Own elaboration.

FIGURE 3

Estimated % changes in the imports of crops and other agricultural under climate change scenarios (full description in Table 2) compared to baseline



Source: Own elaboration.

the application of nitrogen fertilizer or increases in the applications of other agro-chemicals that are likely to increase (Iglesias and Rosenzweig, 2002). The scenarios analysed may not be realistic from a policy point of view but are consistent with estimations of water availability and withdrawals under climate change (Alcamo *et al*., 2003; Arnell, 2004; Doll, 2002; Gleick, 2003). Therefore the results should be considered optimistic from the production point and pessimistic from the environmental point of view, especially when evaluating future vulnerability of ecosystems (Schroter *et al*., 2005; Stoate *et al*., 2001) and water adaptation issues (EEA, 2007).

The economic analysis contributes to the understanding of the relative contributions of the climate and socio-economic changes in the future in the agricultural sector. As presented in Table 6, the monetary estimates show that in all cases the socioeconomic signal –as represented by the A2 and B2 components of the scenario results– has larger implications than the climate signal –as represented by the HadCM3 and ECHAM4 global climate models. The relative implications of the climate and socio-economic signals are best captured by translating the agricultural production results into monetary estimates that take into account the reallocation of factors.

Adaptation options at the local level and regional level are extensive (Burton and Lim, 2005; Easterling *et al*., 2003). For example, at the local level adaptation initiatives may combine water efficiency initiatives, engineering and structural improvements to water supply infrastructure, agriculture policies and urban planning/management. At the national/regional level, priorities include placing greater emphasis on integrated, cross-sectoral water resources management, using river basins as resource management units, and encouraging sound and management practices. Given increasing demands, the prevalence and sensitivity of many simple water management systems to fluctuations in precipitation and runoff, and the considerable time and expense required to implement many adaptation measures, the agriculture and water resources sectors in many areas and countries will remain vulnerable to climate variability. Water management is partly determined by legislation and co-operation among government entities, within countries and internationally; altered water supply and demand would call for a reconsideration of existing legal and cooperative arrangements.

Adaptation is, in part, a political process, and information on options may reflect different views about the long-term future of resources, economies, and society. The capacity to adapt to environmental change is implicit in the concept of sustainable development and, implies an economic as well as a natural resource component. Perception of environmental and economic damage is also a driver of the economic component of adaptation. Adaptation is limited due to limits in resources, technology, and especially social, cultural, and political constraints, such as acceptance of biotechnology, rural population stabilization may not be optimal land use planning, and acceptance of water price and tariffs.

Finally, climate change, population dynamics, and economic development will likely affect the future availability of water resources for agriculture differently in different regions. The demand for, and the supply of, water for irrigation will be influenced not only by changing hydrological regimes (through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales), but by concomitant increases in future competition for water with non-agricultural users due to population and economic growth (Vorosmarty *et al*., 2000).

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