

**PROJECTIONS OF ECONOMIC IMPACTS OF CLIMATE CHANGE IN
AGRICULTURE IN EUROPE**

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Projections of economic impacts of climate change in agriculture in Europe

Summary

The objective of this study is to provide monetary estimates of the impacts of climate change in European agricultural sector. The future scenarios incorporate socio-economic projections derived from several socio-economic scenarios and experiments conducted using global climate models and regional climate models. The quantitative results are based simulations using the GTAP general equilibrium models system that includes all relevant economic activities. The estimated changes in the exports and imports of agricultural goods, value of GDP and value of world supply under the climate and socio-economic scenarios show significant regional differences between northern and southern European countries. The simulations were based on crop productivity changes that considered no restrictions in water availability for irrigation or restrictions in the application of nitrogen fertilizer. Therefore the results should be considered optimistic from the production point and pessimistic from the environmental point of view. Water restrictions and socio-economic variables that modify the probabilities of change occurring may also be considered in a later stage of the study. The monetary estimates show that in all cases uncertainty derived from socio-economic scenarios has a larger effect than the derive from climate scenarios.

Key words: climate change, agriculture, general equilibrium models

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Projections of economic impacts of climate change in agriculture in Europe

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). The effects of climate change on agriculture vary between different regions and different scales (global, regional and local). Many studies document the implications of climate change for agriculture and pose a reasonable concern that climate change is a threat to poverty and sustainable development, especially in marginal areas. Nevertheless, the relationships between climate change and agriculture are complex, because they involve climatic and environmental aspects (physical effects) and social and economic responses.

The Stern Review of the Economics of Climate Change (Stern et al., 2006) argues that “the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP¹ each year. This has been challenged by many economists with large working experience in climate change (Tol, 2007) since it ignores and contradicts numerous unquestionable results (Nicholls and Tol, 2005; Nordhaus, 2006; Sachs, 2001; Fankhauser and Tol, 2005).

At the global level, most economic valuations have focussed on the impacts of climate change in food security (Gregory et al., 2005; Parry et al., 2004; Parry et al., 2001

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. 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 (Conrad, 2007).

The objective of this study is to provide monetary estimates of the impacts of climate change in European agricultural sector. The future scenarios incorporate socio-economic projections derived from several socio-economic scenarios and experiments conducted using global climate models and regional climate models (Iglesias et al., 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 and potential water demand allowing the evaluation of possible policy adaptation options in the future for a range of climate scenarios in different agricultural regions. Water restrictions and socio-economic variables that modify the probabilities of change occurring may also be considered in a later stage of the study.

Methods and data

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 CO₂ concentrations, and water availability. Iglesias et al. (2007) estimated crop production functions at the regional level taking into account water supply and demand, social vulnerability and adaptive capacity. 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 socio-economic variables (i.e., population, technology, economic development, etc) that result in different greenhouse gas emissions (i.e., CO₂ 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>).

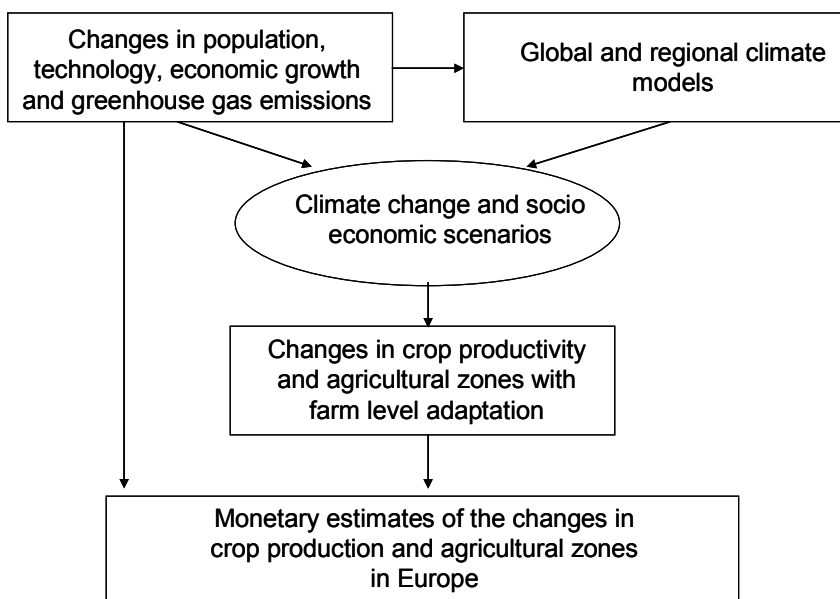


Figure 1 Summary of the approach

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 (2007). 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, fertilizer inputs, and management constraints. 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.

Socio-economic scenarios

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 below.

THE HETEROGENEOUS WORLD SCENARIOS (SRES A2)

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:

- Agriculture: Lower levels of wealth and regional disparities.
- Natural ecosystems: Stress and damage at the local and global levels.
- Coping capacity: Mixed but decreased in areas with lower economic growth.
- Vulnerability: Increased

THE LOCAL SUSTAINABILITY SCENARIOS (SRES B2)

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:

- Agriculture: Lower levels of wealth and regional disparities.
- Natural ecosystems: Environmental protection is a priority, although strategies to address global problems are less successful than in other scenarios. Ecosystems will be under less stress than in the rapid growth scenarios.
- Coping capacity: Improved local
- Vulnerability: 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. (Adapted from the Special Report on Emission Scenarios, IPCC SRES, 2001)

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

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 (PURDENCE, 2006)

Table 2 Summary of the five climate scenarios used in the study (source: Peseta project, <http://peseta.jrc.es/index.htm>)

Scenario	Time frame	Driving Socio-economic scenario SRES	Driving Global climate models (GCM)	Regional climate models	Average CO2 ppmv	Change in average annual temperature averaged in Europe (deg C)
HadCM3 A2 / DMI/HIRHAM 2080s	2071-2100	A2	HadCM3	DMI/HIRHAM	709	3.1
HadCM3 B2 / DMI/HIRHAM 2080s	2071-2100	B2	HadCM3	DMI/HIRHAM	561	2.7
ECHAM4/OPYC3 A2 / SMHI/RCA3 2080s	2071-2100	A2	ECHAM4	SMHI/RCA3	709	3.9
ECHAM4/OPYC3 B2 / SMHI/RCA3 2080s	2071-2100	B2	ECHAM4	SMHI/RCA3	561	3.3
ECHAM4/OPYC3 A2 / SMHI/RCA3 2020s	2011-2040	A2	ECHAM4	SMHI/RCA3	424	1.9

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 equilibria 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.

REGIONAL, SECTOR AND FACTOR AGGREGATION

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

Crops	Paddy rice, wheat, cereal grains, processed rice, vegetables, fruits and nuts, oil seeds, sugar cane and sugar beet, plant based fibres, crop mix, vegetable oils and fats 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

CHANGES IN CROP PRODUCTION

Following Bosello and Zhang (2005), we first pseudo-calibrate the model, deriving a baseline equilibrium “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 (IMAGE Team, 2001) 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. The physical impacts on agriculture (Table 4) were estimated at the grid level and aggregated over agroclimatic areas (see <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 HadCM3/HIRHAM A2 and B2 scenarios for the 2080s and for the ECHAM4/ RCA3 B2 scenarios for the 2020s 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)	
	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %	Yield Change %	SD %
Region										
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

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) SRES (2001) listed on Table 6. 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

Results

Spatial effects

The physical impacts on agriculture aggregated into country level are in Table 6. The yield changes include the direct positive effects of CO₂ 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.

Table 6 Average % changes by country in crop yield under the HadCM3/HIRHAM A2 and B2 scenarios for the 2080s and for the ECHAM4/RCA3 B2 scenarios for the 2030s 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

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 8 respectively.

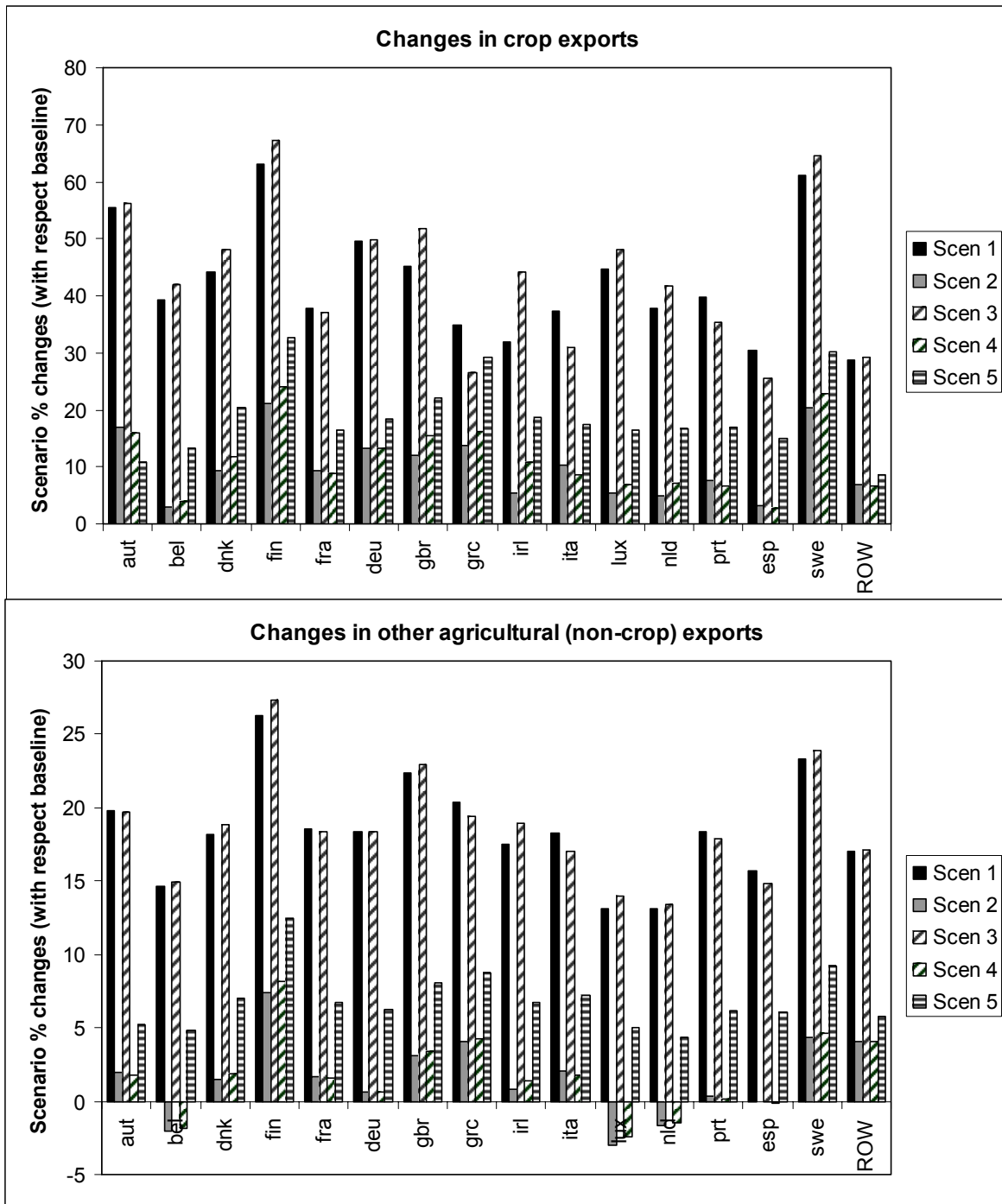


Figure 2 Estimated % changes in the exports of crops and other agricultural under the climate and socio-economic scenarios with respect to the baseline

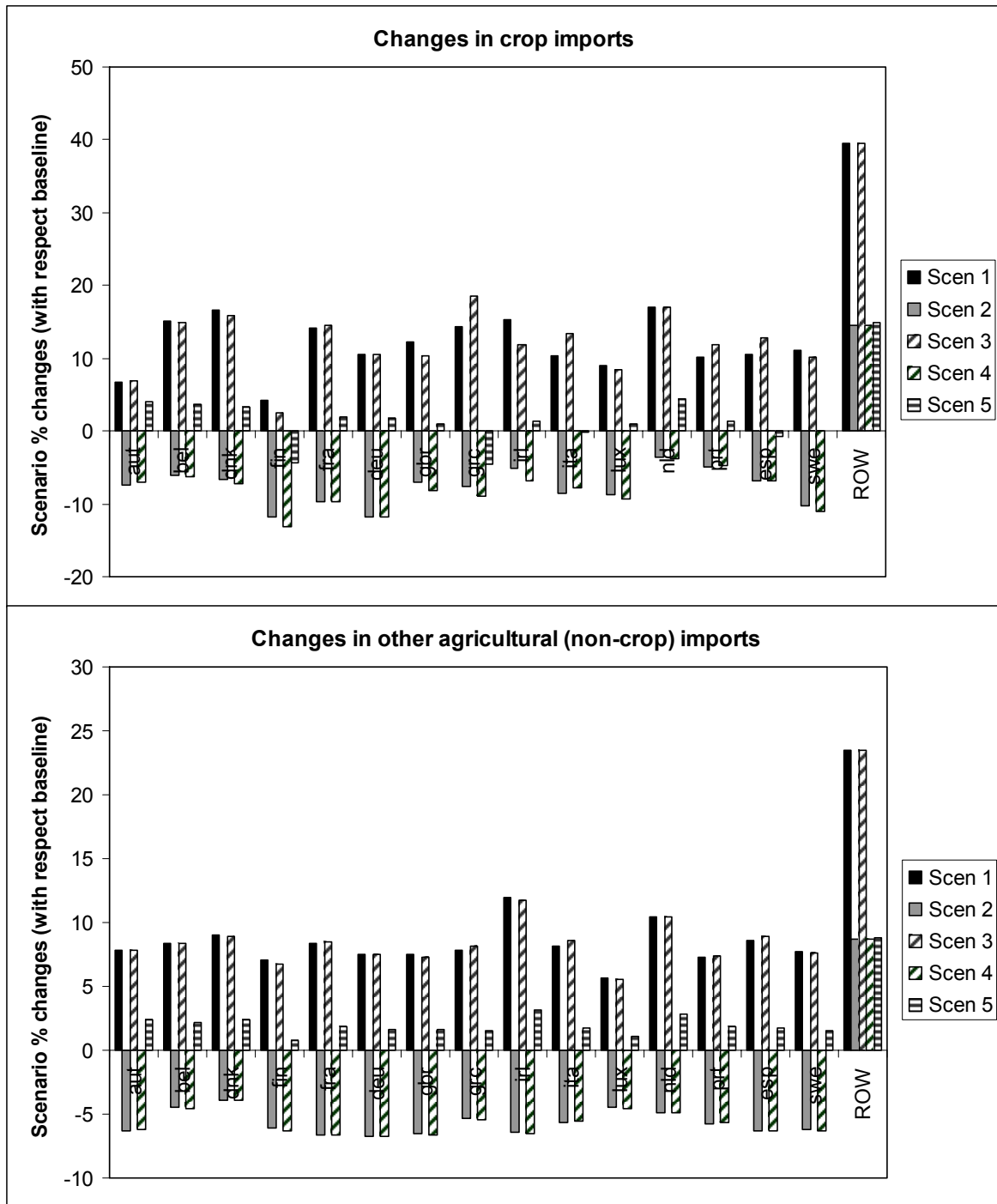


Figure 3 Estimated % changes in the imports of crops and other agricultural under the climate and socio-economic scenarios with respect to the baseline

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 seems 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.

Table 7 % Change in Value of GDP (with respect 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	-0.62315	-0.21479	-0.62837	-0.21342	-0.21918
Belgium	-0.59914	-0.20624	-0.59693	-0.20073	-0.19697
Denmark	-0.19499	-0.16857	-0.17348	-0.14926	-0.02368
Finland	-0.74488	-0.23835	-0.74942	-0.23518	-0.24684
France	-0.48913	-0.14722	-0.49502	-0.14586	-0.14816
Germany	-0.59521	-0.20167	-0.59891	-0.19839	-0.19217
United Kingdom	-0.68181	-0.16832	-0.67740	-0.16015	-0.20787
Greece	-0.46473	-0.00970	-0.51854	0.00851	-0.03743
Ireland	-0.59134	-0.25227	-0.58872	-0.24606	-0.19246
Italy	-0.61355	-0.17152	-0.64365	-0.17477	-0.17659
Luxembourg	-0.69643	-0.13365	-0.69179	-0.12123	-0.18901
The Netherlands	-0.17218	-0.19748	-0.14234	-0.17623	-0.02547
Portugal	-0.61564	-0.21303	-0.62658	-0.21213	-0.20115
Spain	-0.38210	-0.16216	-0.42700	-0.16206	-0.07852
Sweden	-0.65281	-0.21333	-0.65411	-0.20743	-0.20372
Rest of the World (ROW)	-0.03629	0.02035	-0.03779	0.02232	0.00566

Table 8 % Change in Value of World Supply (with respect to baseline)

	HadCM3/ HIRHAM A2 2080	HadCM3/ HIRHAM B2 2080	ECHAM4/ RCA3 A2 2080	ECHAM4/ RCA3 B2 2080	ECHAM4/ RCA3 A2 2030
Crops	36.42535	11.60736	36.49967	11.58378	13.14486
Other Agrarian Goods	19.68392	5.20030	19.69489	5.19441	7.08223
Manufactures and Services	-2.08048	-0.59745	-2.08553	-0.59315	-0.72392

Comparing the results in Table 7 and Table 8 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.

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 (Long et al., 2004; 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 (2007) 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 the application of nitrogen fertilizer or increases in the applications of other agro-chemicals that are likely to increase (Chen and McCarl, 2001; 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 (Berry et al., 2006; Schroter et al., 2005; Stoate et al., 2001) and water adaptation issues (EEA, 2007).

The monetary estimates show that in all cases the socio-economic signal has a larger effect over economic results than the climate signal. That is relevant since the physical effects studies can not capture this effect, while don't take into consideration the reallocation of factors.

Adaptation options at the local level and regional level are extensive (Brooks et al., 2005; Burton and Lim, 2005; Burton et al, 2002; 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 (Downing, 2005). 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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