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Climate Change and Agriculture in 2050:

Assessing Prospects for European Cereal and Oilseed Markets

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicts an average global temperature increase by nearly 3 °C and potentially increased frequency of extreme weather events, sea level rise, and changed precipitation patterns (IPCC, 2007). Given the vulnerability of the agricultural sector to variations in weather conditions, it will be one of the most vulnerable sectors to climate change and production will be substantially affected in most parts of the world. However, impacts vary upon regions and crops (Rosenzweig and Perry, 1994).

Against this background, the main objective of this study is to simulate economic impacts of climate change on European cereal and oilseed markets at the member state level. Based on the predicted productivity changes from the joint application of a dynamic vegetation model (Müller et al., 2009), economic impacts of climate change are modelled with the European Simulation Model (ESIM). ESIM is a partial equilibrium model which depicts the agricultural sector of the EU in substantial detail and the rest of the world in a highly aggregated form. A closely connected purpose of this study is to consider climate change induced adaptation of farmers to changes in the relative profitability of crops.

Chapter 2 explains the most prominent methods used to measure economic impacts of climate change on agricultural markets and highlights their advantages and disadvantages. The following chapter describes the market model used for this study and explains the methodological approach. Chapter 4 briefly introduces the scenario assumptions before interpreting results in Chapter 5. Finally, conclusions are drawn in the last chapter.

2. Modelling Climate Change Impacts

Over the past two decades, a variety of methods and modelling techniques have been developed to measure the impact of climate change on agriculture. One can, however, classify

most studies according to whether they are “agriculturally oriented” or “economically oriented” (Bosello and Zhang, 2005).

Agriculturally oriented studies focus on the explicit productivity impacts of changing climatic conditions on crops and their growing conditions, while economically oriented studies instead analyze agricultural market reactions to climate change based on simple crop response mechanisms only. Past literature distinguishes primarily three prominent methods which have been developed to analyze the impact of climate change on agricultural production and its economic impacts: the Ricardian approach, the Agro-Ecological Zones approach (AEZ), and crop simulation models (Rosenzweig and Parry, 1994; Adams et al., 1990; Mendelsohn et al., 1994, Fischer et al., 2005). The Ricardian method directly links climate change to farm income, whereas the crop model and AEZ approach link productivity outcomes to economic models and can thus also be called indirect methods. The method used for this paper is also based on that indirect approach since crop model results are linked to an agricultural market model.

The next sections describe the three methods and identify their advantages and disadvantages.

2.1 Ricardian Approach

Also referred to as the cross-section model, the Ricardian approach relates agricultural capacity statistically to temperature and precipitation based on farm survey or county data of a certain region (Cline, 2007). This approach is based on the classical economist David Ricardo’s theory that the net value of land reflects its net productivity (Ricardo, 1817). Constituted on Ricardo´s theory, Mendelsohn, Nordhaus and Shaw (1994) developed an impact model that uses statistical regressions of land values, or net revenue, per hectare on climatic data and other factors such as a variety of fundamental geographic, geophysical,

agricultural, economic, and demographic factors to determine the intrinsic value of climate on farmland (Mendelsohn et al., 1994).

Their basic hypothesis is that climate change shifts the production function for crops and that farmers take environmental variables as given, adjusting their inputs and outputs accordingly (Mendelsohn et al., 1994). This approach automatically incorporates efficient adaptations to climate change by farmers. Since it relies upon comparisons over vast landscapes, it is thus able to represent actual farm conditions; however, since the Ricardian model links climate directly to net income it is not able to account for any crop specific changes, nor is it able to consider potential CO2-fertilization effects (Adams et al., 1998).

Studies using the Ricardian approach to measure climate impacts on agriculture have, for example, been done for Latin America (Seo and Mendelsohn, 2007) the US (Mendelsohn et al., 1994), Egypt (Eid et al., 2007) and countries in Africa (Maddison et al., 2007).

2.2 Agro-Ecological Zones Approach

The Agro-ecological Zones (AEZ) approach is a GIS-based modelling framework that combines land evaluation methods with socioeconomic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture (Fischer et al., 2006).

It uses agronomic based knowledge to simulate the availability and use of land resources, options for farm-level management, and potentials of crop production as a function of climate (Riahi et al., 2006). Outcomes are then linked to the world agro-economic model BLS (Basic Linked System). The BLS is a general equilibrium model system which represents all economic sectors and links countries through trade, world market prices, and financial flows (IIASA, 2009). A disadvantage of BLS is that predicted potential yields from AEZ models are often much larger than current actual yields. Hence critics argue that the models may overestimate the effects of autonomous adaptation and claim that AEZ studies tend to

overestimate benefits of warming in cold high-latitude regions, thereby overstating global gains from climate change (Cline, 2007). The AEZ approach is primarily used to study climate change impacts on a global scale (Fischer et al., 2005; Parry et al., 1999).

2.3 Crop Models

The other seminal method broadly used for measuring climate change impacts on agriculture is crop model analysis (Rosenzweig and Parry, 1994). Crop simulation models are based on experiments where crops are grown in field or laboratory settings under different simulated climates and CO2 levels. Farmer's potential adaptation measures can also be included in the crop models, such as changes in planting dates, choice of variety and crop, and applications of irrigation and fertilizer. Nevertheless, it has to be taken into account that the level of adaptation is subject to uncertainty since the scope of adaptation is limited to assumptions made by the modeller. The field or laboratory experiments are then extrapolated over regions. This is a disadvantage of crop models compared to the Ricardian method which compares actual farm conditions over many regions (Mendelsohn, 2007).

Many climate impact studies use crop models to predict future crop productivity changes. In particular, such crop models are useful regarding climate change impact assessments since they are able to simulate the effects of elevated CO2 concentrations on agricultural production (Tubiello and Ewert, 2002). A large body of work has been devoted to analyzing such potential impacts on future local, regional and global crop production (e.g., Rosenzweig and Parry, 1994; Rosenzweig et al., 1995; Fischer et al., 2001; Reilly et al., 2001). In the majority of these studies, crop models were employed to assess the simultaneous effects on crop growth and yield of future elevated CO2 concentrations, regional climate change, and adaptation measures. To translate crop model results into economic effects, they are linked with general or partial equilibrium models such as GTAP, the Basic Linked System (BLS) or IMPACT (Fischer et al., 2005; Rosenzweig and Parry, 1994; Parry et al., 2004; Nelson et al.

2009). There is a huge variety of crop models and incorporated approaches to modelling the effects of elevated CO2 concentrations and its interaction with other important factors on plant physiology such as temperature and precipitation. This heterogeneity makes it difficult to compare results (Tubiello and Ewert, 2002).

Generally two different kinds of crop models can be distinguished: statistical models and process-oriented models. Statistical models predict agricultural yields for large regions based on regression analysis on monthly or annual variables. The process models, in turn, compute crop dynamics at small scales such as leaf to canopy or field levels (Tubiello and Ewert, 2002). The vegetation model LPJ used for this study, which is described in the section below, belongs to the family of process-oriented models.

2.4 LPJ Model

The Lund-Potsdam-Jena (LPJ) model is a so-called dynamic global vegetation model (DGVM) which has been developed as an intermediate complex model that can potentially be used for a broad range of applications. It represents land-atmosphere coupling and explicitly includes major processes of vegetation dynamics. Vegetation is described in grid cells in terms of ten different plant functional types (PFTs). PFTs are differentiated by physiological, morphological, phonological, bioclimatic and fire-response attributes. It also includes explicit representation of vegetation structure, dynamics, competition among PFT populations, and soil biogeochemistry (Sitch et al., 2003; Smith et al., 1997)[3].

The productivity changes due to climate change of major crops implemented in ESIM which we use for this paper were computed by Bondeau et al. (2009). They include effects of climate change and CO2 fertilization on yields of major crops globally at a spatial resolution of 0.5°x0.5°. Yield simulations are based on process-based implementations of gross primary production, growth- and maintenance respiration, water-stress, and biomass allocation,

[3] For a detailed description of the model see Sitch et al., (2003) and Prentice et al., (1992).

dynamically computing the most suitable crop variety and growing period in each grid cell as described in more detail by Bondeau et al. (2007).

3. ESIM – Description of the model

3.1 General Overview

ESIM is a comparative static, net trade, partial equilibrium model of the European agricultural sector (Banse, Grethe and Nolte, 2005). The version of the model used for this study has the base period 2005 and includes 27 EU Members, Turkey and the US. All other countries are aggregated in one region, the so-called rest of the world (ROW). ESIM covers 15 major crops, 6 animal products, 14 processed products and a range of other products such as pasture and voluntary set aside. ESIM is mainly designed to simulate the development of agricultural markets in the EU and accession candidate countries. Hence, policies are modelled in great detail for these countries. All behavioral functions in ESIM excluding area allocation for sugar are isoelastic. Supply at the farm level is defined for 15 crops, 6 animal products, pasture and voluntary set-aside. Human demand is defined for processed products and for most farm products. Some of these products enter only the processing industry, e.g. rapeseed, and others are used only in feed consumption, e.g. fodder or grass from permanent pasture. The price formation mechanism in ESIM assumes an EU point market for all products except for non-tradables (potatoes, milk, grass, fodder). Domestic price formation in the EU depends on endogenous world market prices, EU market and price policies, and the EU net trade position.

3.2 Methodological Approach to Depict Climate Change Effects in ESIM

Climate change induced impacts on crop productivity are shocks on the supply-side. In ESIM, such effects are introduced as changes in average national yields. Supply of crops in the EU is defined as area multiplied by yield, whereby yield and area functions are specified separately.

Yield is dependent on own price, the price index of non-agricultural inputs and a productivity shifter. The latter reflects rates of technical progress as well as climate change induced productivity changes. The degree to which productivity will potentially decline or increase is provided by the Potsdam Institute for Climate Impact Research derived from the vegetation model LPJ (Bondeau et al., 2009).

To account for farmer´s adaptation to changes in relative productivity of crops, area allocation functions are shifted based on yield trends and elasticities with respect to yield trends. These elasticities were derived based on yield driven cost changes generated by the farm level model FARMIS (Offermann et al., 2005).

3.2.1 Supply in ESIM

In European countries, supply of crops is modelled as a two-stage function, consisting of an area element which is multiplied by a yield element (1). In other countries, supply is a direct function of own and cross producer prices as well as technical progress.

Thereby, yield is a function of the own price (PP), the costs for labor (labor) and intermediate inputs (intermed), and a productivity shifter (trend) (2). The area allocation process takes place in two steps. First (3), area is allocated as a function of own and cross incentive prices[4] (PI) as well as a labor, capital and intermediate cost indexes. In a second step, the area allocated to all crops covered by the model is summed and the resulting total area is scaled down (except obligatory set-aside area) in case the total base area is exceeded.

(1) $SUPPLY_{cc,cr} = AREA_{cc,cr} \cdot YIELD_{cc,cr}$

[4] Incentive prices are the sum of farm gate prices and area based direct payments multiplied by a decoupling factor.

$$(2) YIELD_{c,cr} = \exp\left[\begin{array}{l} ln\,\text{yield int}_{c,cr} + \sum_{cr}\left(\varepsilon_{c,cr} * ln\,\text{PP}_{c,cr}\right) \\ \\ + \ \delta\ ln\,\text{intermed} \\ + \ \mu\ ln\,\text{labor} \\ + \ ln\,\text{trend} \end{array}\right]$$

With: yield int-yield intercept, PP-Producer Price, ε- elasticity of yield with respect to own price, δ- elasticity of yield with respect to costs of intermediates, μ- elasticity of yield with respect to labor costs, and trend parameter.

$$(3) AREA_{c,cr} = \exp\left[\begin{array}{l} \ln\,\text{area int}_{c,cr,j} + \sum_{j}\left(\varepsilon_{c,cr,j} * \ln\,\text{PI}_{c,j}\right) \\ \\ + \ \lambda\ \ln\,\text{capital} \\ + \ \mu\ \ln\,\text{labor} \\ + \ \delta\ \ln\,\text{intermed} \\ + \ \beta\ \ln\,\text{trend} \end{array}\right]$$

With: *area* int-area intercept, PI-incentive price, ε- elasticity of area allocation with respect to incentive prices, λ- elasticity of area allocation with respect to capital costs, μ- elasticity of area allocation with respect to labor costs, δ- elasticity of area allocation with respect to costs of intermediates, and β- elasticity of area allocation with respect to yield trends.

Own price, cross price, and input price elasticities of supply are calibrated to fulfil the conditions derived from economic theory, which are homogeneity of degree zero in input and output prices, symmetry of cross price effects, and non-negativity of the own price effect.

3.2.2 Adjusting Yield Trends

Technological progress shifters applied in the crop supply of ESIM are based on a yield trend analysis from FAOSTAT data of the period 1992 to 2007. For any climate change scenarios,

an additional component was added to these shifters to incorporate productivity changes from climate change.

The vegetation model LPJ delivered mean yield changes for the period 1996-2005 to 2046-2055 based on climate data from the Global Circulation Model ECHAM. Based on the percentage yield changes from the vegetation model, an annual growth rate was derived and added to the technical progress shifter "trend" in the log linear yield function (2). Technical progress shifters for the baseline as well as all climate change scenarios, with and without a CO2-fertilization effect, are shown in %/year in Table 1-5 for selected European countries, the US, and aggregated non European countries and regions (NEU[5]) and the aggregated world (WO).

3.2.3 Adaptation – Area Allocation

An important issue concerning the magnitude of economic effects in the agricultural sector from climate change are adaptation measures at the farm level. Available strategies include short-term adjustments as well as long-term adaptations. Short-term adjustments include efforts to optimize production without major system changes and can be classified as being autonomous since no other sectors, such as policy and research, influence their development and implementation. Examples of short-term adjustments include changes in varieties, sowing dates and fertilizer use (Olesen and Bindi, 2004).

Farmers allocate their acreage to crops according to their relative profitability based on input and output prices and yields. The area allocation decision can also be classified as short-term adjustment. However, most partial equilibrium models, such as IMPACT (Nelson et al., 2009) and the standard version of ESIM, define area allocation as purely price driven and hence do not account for farmers' yield level related decisions. As a result, these models would underestimate the supply effect of an increase in the relative yield for any crop. Other

[5] consisting of Turkey, the US and the ROW.

approaches, such as CAPRI, take changes in yield levels automatically into account by modelling area allocation as a function of gross margins (Britz, 2005). Nonetheless, such approaches require substantial data on country level production costs and do not fit the aspired simple structure of ESIM.

Against this background we consider farmers' reaction to changes in climate induced yield levels by shifting area allocation functions: we add yield shifters to the power of the elasticities of area allocation with respect to own and cross yield shifters. Elasticities are derived based on own price elasticities of area allocation corrected for yield driven cost changes generated by the farm level model FARMIS[6] (Offermann et al., 2005). We begin with the assumption that without any cost changes in case of higher yield trends, an increase in yield would have the same effect on area allocation as an increase in price, i.e. elasticities of area allocation with regard to own and cross yield trends would equal own and cross price elasticities of area allocation. Yet, knowing that higher yields go together with higher costs, especially input costs for fertilizer, we expect elasticities of area allocation with respect to yield trends to be lower.

We approximated the increase in costs in case of higher yield trends based on FARMIS by running the model with the same climate change induced yield changes as in ESIM for the year 2050 compared to a situation without climate change. The increased/decreased input costs from this "with climate change" scenario in FARMIS were than compared with input

6 EU-FARMIS is a comparative-static process-analytical programming model based on Farm Accountancy Data Network (FADN) data, which aggregates individual farm data into farm groups. Production is differentiated for 27 crop activities and 15 livestock activities. The model specification is based on information from the German farm accountancy data network covering about 11,000 farms, supplemented by data from farm management manuals. Key characteristics of FARMIS are the use of improved aggregation factors that allow for a representation of the sector's production and income indicators, input-output coefficients which are consistent with information from farm accounts, and the use of a positive mathematical programming procedure to calibrate the model to observed base year levels. Fertilizer and pesticide input costs are generated endogenously and serve as a basis for the estimation of elasticities.

costs results from a “no climate change” scenario (see Table 6). With a relative yield increase of about 37% (A1B with CO2-effect) from effects of climate change, input costs for wheat, for example, would increase by an amount equal to 14.1% of revenue more than in the baseline scenario without climate change. This implies that per percent of yield increase, input costs will increase by an amount equaling about 0.38% of revenue. One minus this figure delivers the factor by which the original price elasticities of area allocation are multiplied and implemented in the area allocation function. Through this method factors were derived for wheat, barley, corn, rye, and rapeseed. The mean value of those grains was also used for the categories of other grains and rice. For oilseeds, soybean and sunflower seeds, the same factor that was used for rapeseed was applied. Silage maize elasticities were multiplied with the same factor that was derived for corn (see Table 7).

4. Scenarios

The IPCC established the so-called SRES emission scenarios (*Special Report on Emissions Scenarios*) to account for different potential developments in the 21st century regarding population growth, economic and social developments, technological inventions, environmental management, and use of resources. Those SRES scenarios are broadly categorized in four families, each assuming different socio-economic developments which, in turn, build the base of potential future green house gas emissions and hence different future climate forecasts (IPCC, 2007).

For this paper, the underlying assumption of socio-economic developments from the A1B and B1 scenarios are used. The macro data in ESIM such as population and income growth are adjusted accordingly. The vegetation model LPJ uses climate input data from the global

circulation model ECHAM and the respective CO2-concentration[7]. The projection horizon is 45 years until the year 2050.

For each of the SRES scenarios two scenarios were specified for this paper: one takes the CO2-fertilization effect into account and one does not (further referred to as "with CO2" and "no CO2" scenario, respectively. The base technological progress shifter rates of the yield functions are equal for both baseline scenarios. The shifter rates for the baseline and each scenario are shown in Table 1.

5. Baseline and Scenario Results

5.1 Baseline

For each SRES emission scenario considered for this study (A1B and B1), a baseline scenario without climate change for the time period 2005 – 2050 is defined The only difference between the A1B and B1 baseline scenarios in their implementation in ESIM is the development of income growth according to IPCC projections, with the A1B scenario having a more pronounced income growth rate compared to the B1 scenario (IPPC, 2007). Selected macro shifters driving the baseline scenarios for both SRES emission scenarios are shown in Table 8.

The overall trend of world market prices under the baseline is calibrated to meet projections published by IFPRI for 2050 (Nelson et al., 2009). Demand shifters in the aggregated non-European countries (NEU) are calibrated to approximate IFPRI price projections. Biofuel consumption is calibrated to maintain a share of 10% in total transportation fuels in the European Union (EU). For the aggregated world (WO), the consumption share is calibrated to

[7] with increasing CO2: 532ppm in 2050 in A1B, 488ppm in 2050 in B1
without increasing CO2: constant CO2 concentration 370ppm

4% in 2050[8]. As biofuel production in the model is based on current technologies, the resulting area use for biofuel production is likely to allow for higher shares in total fuel consumption in 2050 as new technologies would allow for higher yields.

Figure 1 depicts the development of average world productivity shifters between 2005 and 2050 for selected crops in the baseline scenarios A1B and B1 without climate change (no CC). Strictly speaking, this is not a model result. Instead, it is just a weighted average based on productivity growth rates presented in Table 1. Highest productivity increases can be seen for corn, rapeseed and sugar, which each have a productivity increase of about 120%.

The aggregated crop supply index for the baseline scenarios (A1B and B1) increases approximately 20% for the EU, 130% for the NEU and 123% for the aggregated WO (see Figure 2) [9]. The world market price indices for crops and livestock products are projected to increase about 42% by 2050 (Figure 2).

5.2 Scenario Results

Climate change impacts productivity of the agricultural sector worldwide. The average world impact on the productivity of selected crops for the period 2005-2050 is shown in Figure 3 (results are based on productivity shifters presented in Table 1).

First, we consider the globally aggregated productivity shifter for the "with CO2" scenarios (Figure 3). Under the A1B scenario, the aggregated changes of the productivity shifters are positive for most crops in comparison to the baseline scenario without climate change. Compared to the baseline scenario, in the A1B scenario the highest productivity increases are for soybean (23%) and sunflower seed (15%). The only crop showing productivity decreases in the A1B scenario is corn, which has a reduced productivity of about 13%. In the B1

[8] Assumption about consumption of transport fuels in 2050 are from the World Energy Outlook 2008, as cited in Fischer (2009).
[9] The high supply increases in the NEU and in the WO compared to the EU can be explained by the fact that we assume total liberalization on European agricultural markets.

scenario, all aggregated productivity shifters are positive and higher for most crops compared to the A1B scenario. The most pronounced relative increases are for soybean and sunflower seed, with 28% and 43%, respectively.

Under the "no CO2" scenario, the aggregated shifters are negative for most crops, except for rye, in the A1B scenario. This is because the EU, where productivity increases, has high shares in world rye production. Relative productivity shifter declines range from 1% for rapeseed to about 27% for sunflower seed as compared to the baseline scenario without climate change. For the B1 scenario, relative changes are positive for some crops, ranging from 1% for corn to about 11% for sunflower seed. Negative results can be observed for a variety of crops compared to the no climate change scnario (Figure 3). There are small declines of about 1% each for barley, soybean and the category "other grains" (OTHGRAIN). Moreover, there are more pronounced declines for wheat and manioc (4%) as well as rice (12%). The very right bar in Figure 3 shows the aggregated world crop productivity shifter. It can easily be seen that under the B1 scenario, for both CO2 scenarios, productivity effects are more positive in comparison to the A1B scenario.

Climate change impacts on agricultural production vary widely among regions. Moreover, these productivity changes can impact food prices. This can be seen in Figures 4 and 5, which shows crop supply and price index changes for the EU, NEU and the WO, for both SRES and CO2-scenarios compared to the baseline.

Not surprisingly, crop supply indices are positive in the A1B "with CO2" scenario compared to the baseline scenario, and the relative supply increase for the EU is greater than it is for the aggregate NEU (8% and 1%, respectively). This results in a 2% aggregated supply increase in the WO. Hence, the price index for crops declines by 17% in the A1B scenario compared to the baseline scenario. This relatively large price increase compared to the small supply increase can be explained by the relatively low demand and supply elasticities incorporated in

the model. Because of the increasing income level, we assume that demand elasticities are about 50% below the level assumed for simulations until 2020, which therefore have a shorter time horizon than our simulations. For example, the own price elasticities of demand in the aggregated ROW are 0.077 for wheat and 0.028 for sunflower oil in our simulations. Under the B1 scenario (Figure 5) the change in the crop supply is even more positive for the EU under the "with" CO2-scenario than it is in the A1B scenario. Compared to the reference scenario without climate change, supply increases about 4% in the NEU and about 5% in the WO under the "with" CO2 scenario. Due to the supply increase in world markets, the crop price index under the B1 "with" CO2 scenario decreases by 19% in comparison to the no climate change scenario. Under the "no CO2" scenarios, increases in crop productivity, and hence crop supply, are smaller. In the A1B scenario, the crop supply index for the EU is still positive (7%) but is less pronounced than it is under the "with CO2" scenario (8%). For NEU, however, relative crop supply decreases by about 4%. Since aggregated supply in the WO declines by 3%, the crop price index increases about 27% compared to the baseline.

Similar results can be observed for the B1 "no" CO2 scenario: however, since aggregated supply in the WO changes marginally only, price effects are less pronounced in comparison to the A1B "no" CO2 scenario (22%).

Livestock prices follow the price development of crop prices which reflects the fact that feed prices have a direct impact on the production costs of livestock products (Figures 4 and 5).

Figures 7 and 8 exemplify how diverse climate impacts are among countries and regions. Effects on Italian and German wheat and corn markets are illustrated for the A1B "with" CO2 scenario compared to the reference scenario. Yield increases for corn and wheat are much higher for Germany than for Italy (47% and 1%, respectively). In both countries, more area is allocated to corn due to higher world market prices. This is caused by the relative decline of

world corn production under the A1B "with" CO2 scenario (10%). On the other hand, less area is allocated to wheat due to a relative price decline since its world supply increases 1%.

6. Concluding Remarks

In this paper we examine potential effects of climate change on European agricultural markets based on scenario simulation up to the year 2050. The simulation scenarios that do consider the CO2-fertilization effect increase aggregated crop production for the EU and to a lesser extend also the NEU under the SRES A1B and B1 scenarios. As expected, a less pronounced increase results under the same scenarios for the EU without CO2-effect. Consequently, with a supply decrease in the NEU under the A1B scenario, crop prices increase compared to the no climate change scenario. Negative impacts are over all less pronounced under the B1 scenario. Impacts of climate change on crop productivity vary greatly among regions. Positive productivity effects for the European Union as a whole can be expected until the year 2050. However, on global scale crop productivity is likely to decrease.

Future extensions of the model will include a depiction of the market effects of yield volatility. To this purpose, a stochastic version of ESIM will be used in which correlated stochastic terms are introduced in the yield functions based on Gaussian Quadratures in order to account for potential climate change induced yield volatility (Artavia et al., 2009).

Further, in order to account for uncertainty regarding future climate predictions, it is planned to run ESIM also with different LPJ derived crop productivity data based on five different global circulation models[10]. This will allow for sensitivity analysis regarding the uncertainty of climate scenarios.

[10] HADCM, GFDL, ECHAM, ECHO-G, CCSM

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APPENDIX

Table 1 : Basic Annual Growth Rate in % of selected Countries/Regions and Crops							
BASE	**FR**	**GE**	**IT**	**US**	***EU***	***NEU***	***WORLD***
WHEAT	0.2	0.8	0.2	0.6	*0.6*	*0.9*	*0.8*
BARLEY	0.6	0.8	0.2	0.4	*1.0*	*0.6*	*0.7*
CORN	0.6	1.3	0.5	1.8	*1.3*	*1.8*	*1.7*
RAPSEED	0.6	2.2	0.5	0.5	*1.6*	*1.8*	*1.7*
SUNSEED	0.9	0.3	0.3	0.5	*1.3*	*0.6*	*0.7*
Table 2: Additional Annual Growth Rates in % A1B Scenario with CO2-Effect							
A1B with CO2	**FR**	**GE**	**IT**	**US**	***EU***	***NEU***	***WORLD***
CWHEAT	0.3	0.4	0.3	0.4	*0.4*	*0.1*	*0.1*
BARLEY	0.3	0.4	0.3	0.4	*0.3*	*0.0*	*0.2*
CORN	0.0	0.9	0.0	0.1	*0.0*	*0.1*	*0.1*
RAPSEED	0.2	0.7	0.2	1.4	*0.5*	*0.1*	*0.2*
SUNSEED	-0.5	0.7	-0.3	0.3	*0.0*	*0.4*	*0.3*
Table 3: Additional Annual Growth Rates in % A1B Scenario without CO2-Effect							
A1B w/o CO2	**FR**	**GE**	**IT**	**US**	***EU***	***NEU***	***WORLD***
CWHEAT	0.0	0.1	0.0	0.1	*0.1*	*-0.2*	*-0.2*
BARLEY	0.0	0.1	0.0	0.1	*0.0*	*-0.2*	*-0.1*
CORN	-0.3	0.6	-0.2	-0.2	*-0.4*	*-0.1*	*-0.2*
RAPSEED	0.0	0.5	0.0	1.0	*0.3*	*-0.2*	*0.0*
SUNSEED	-1.9	0.1	-1.5	-0.7	*-0.8*	*-0.7*	*-0.7*
Table 4: Additional Annual Growth Rates in % B1 Scenario with CO2-Effect							
B1 with CO2	**FR**	**GE**	**IT**	**US**	***EU***	***NEU***	***WORLD***
CWHEAT	0.2	0.4	0.2	0.2	*0.4*	*0.0*	*0.1*
BARLEY	0.2	0.4	0.2	0.2	*0.3*	*0.1*	*0.2*
CORN	0.3	1.1	0.2	0.2	*0.4*	*0.1*	*0.2*
RAPSEED	0.1	0.6	0.2	0.6	*0.5*	*0.2*	*0.3*
SUNSEED	0.5	0.6	1.0	0.5	*0.7*	*0.8*	*0.8*
Table 5: Additional Annual Growth Rates in % B1 Scenario without CO2-Effect							
B1 w/o CO2	**FR**	**GE**	**IT**	**US**	***EU***	***NEU***	***WORLD***
CWHEAT	0.0	0.2	0.0	0.0	*0.2*	*-0.2*	*-0.1*
BARLEY	0.0	0.2	0.0	0.0	*0.1*	*-0.1*	*0.0*
CORN	0.1	0.9	0.1	0.0	*0.2*	*0.0*	*0.0*
RAPSEED	-0.1	0.4	0.0	0.9	*0.3*	*0.0*	*0.1*
SUNSEED	-0.2	0.2	0.4	0.2	*0.2*	*0.3*	*0.2*

Table 6: Input costs in % of revenue compared to baseline scenario w/o climate change and change in crop yields in % compared to baseline scenario in 2050 (A1B with CO2-effect)

	Δ% Cost	Δ % Yield	Δ Costs in % of revenue	Factor
Colum:	(1)	(2)	(3)=(1)/(2)	(4) = 1-(3)
Wheat	14.1	37	0.3811	0.6189
Barley	6.5	18	0.3611	0.6389
Corn	19.9	64	0.3109	0.6891
Rye	1.8	5	0.3600	0.6400
Rapeseed	12	27	0.4444	0.5556

Table 7: Factor for multiplication of area allocation elasticities

WHEAT	0.6189	**OTH GRAINS**	0.6412
BARLEY	0.6389	**RICE**	0.6412
CORN	0.6891	**SMAIZE**	0.6891
RYE	0.6400	**RAPSEED**	0.5556
SOYBEAN	0.5556	**SUNSEED**	0.5556

Table 8: Annual growth rate for both SRES emission scenarios - 2050

A1B	**EU**	**FR**	**UK**	**ROW**
Population	-0,10	0,27	0,17	0,78
Income	3,28	1,91	1,91	5,49
B1	**EU**	**FR**	**UK**	**ROW**
Population	-0,10	0,27	0,17	0,78
Income	2,78	1,71	1,71	4,98

Figure 1

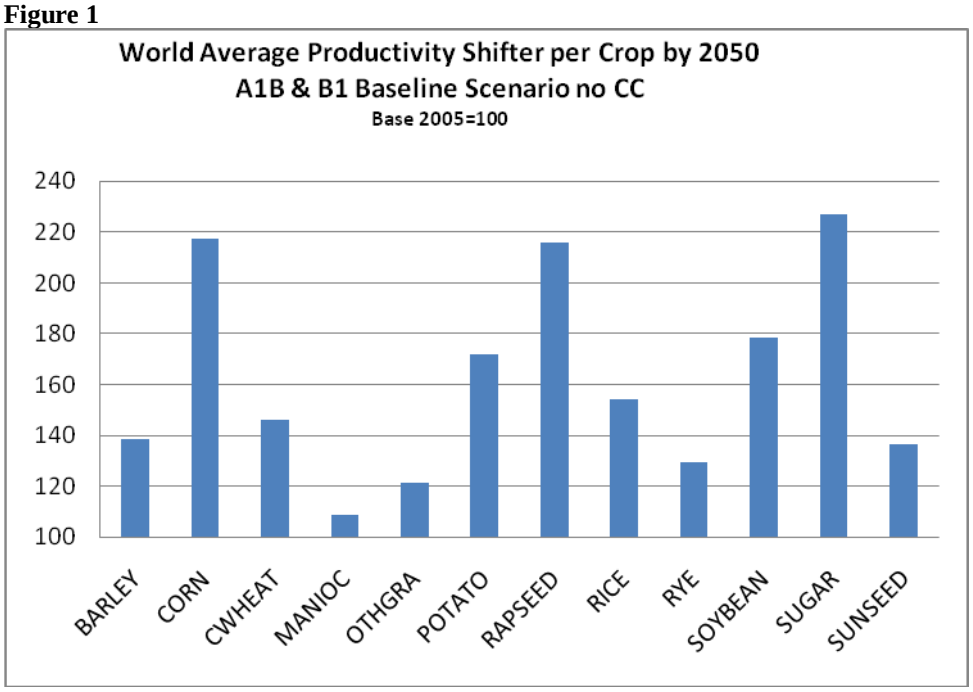


Figure 2

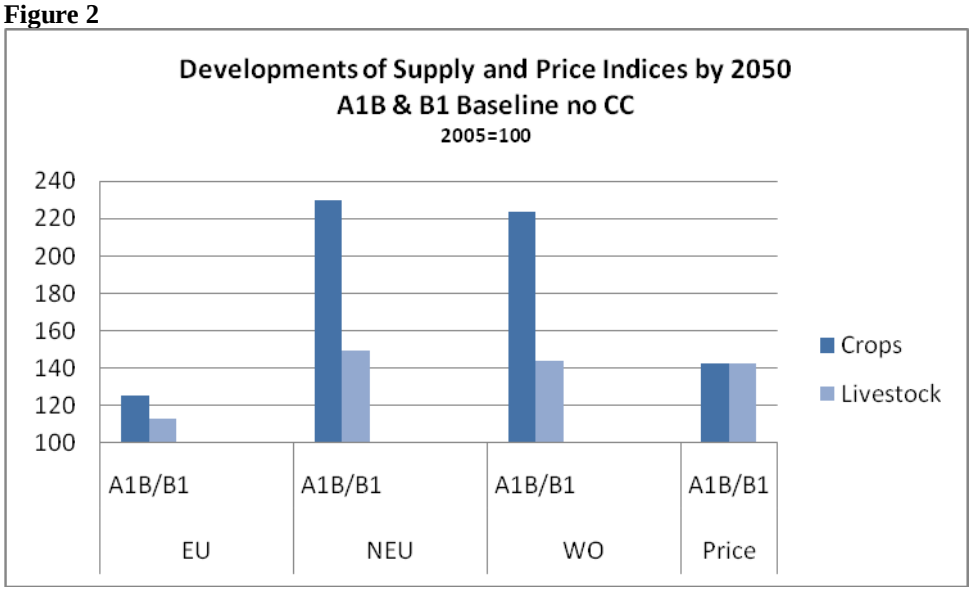


Figure 3

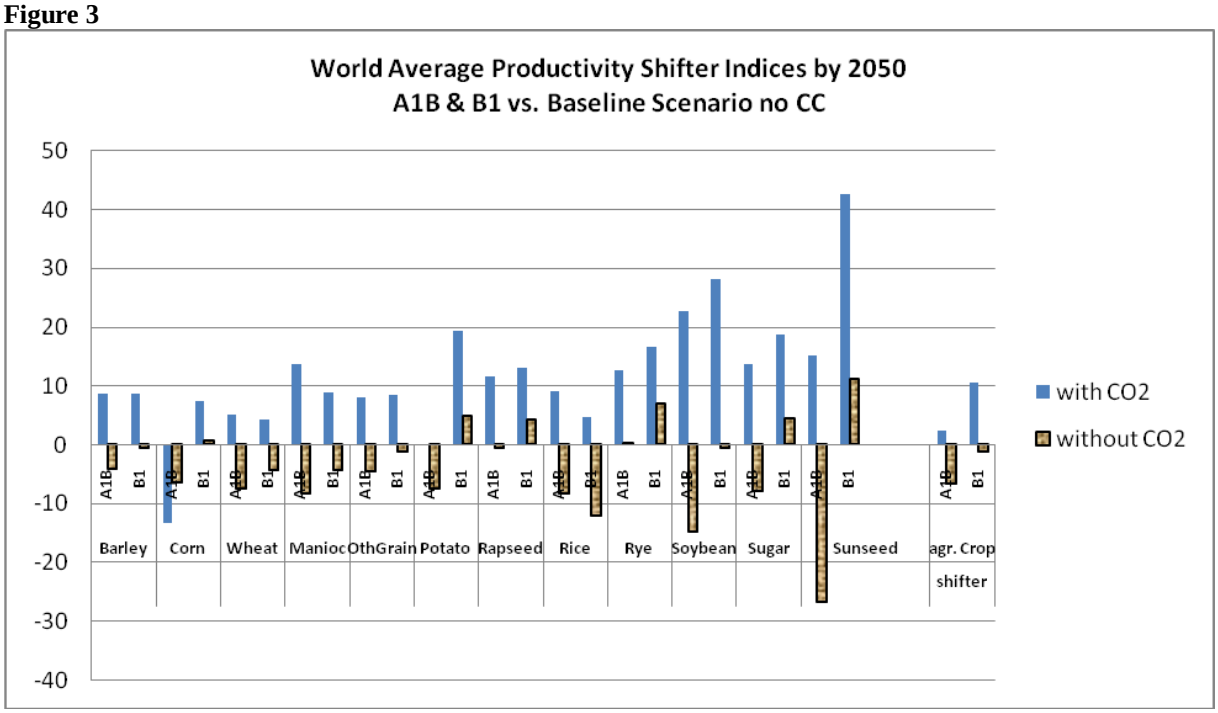


Figure 4

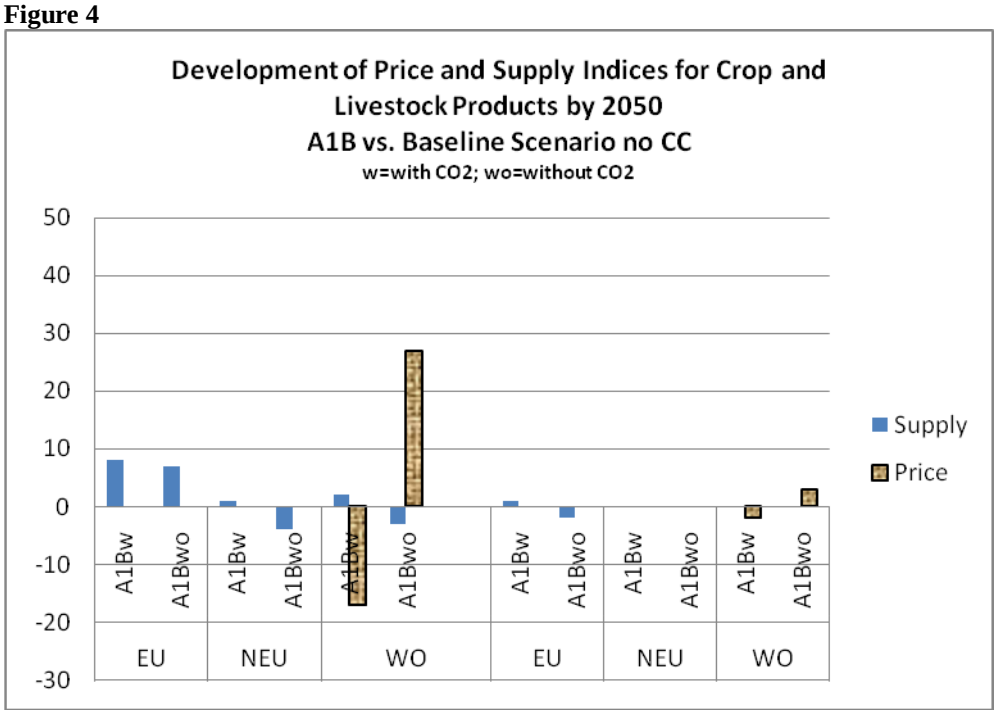


Figure 5

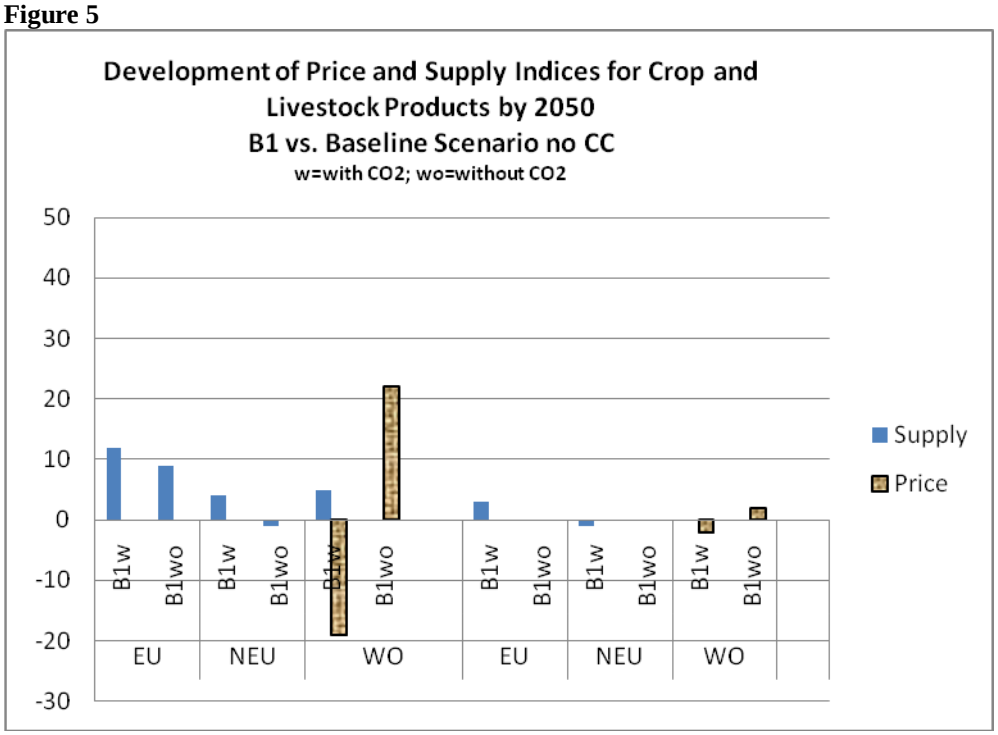


Figure 6

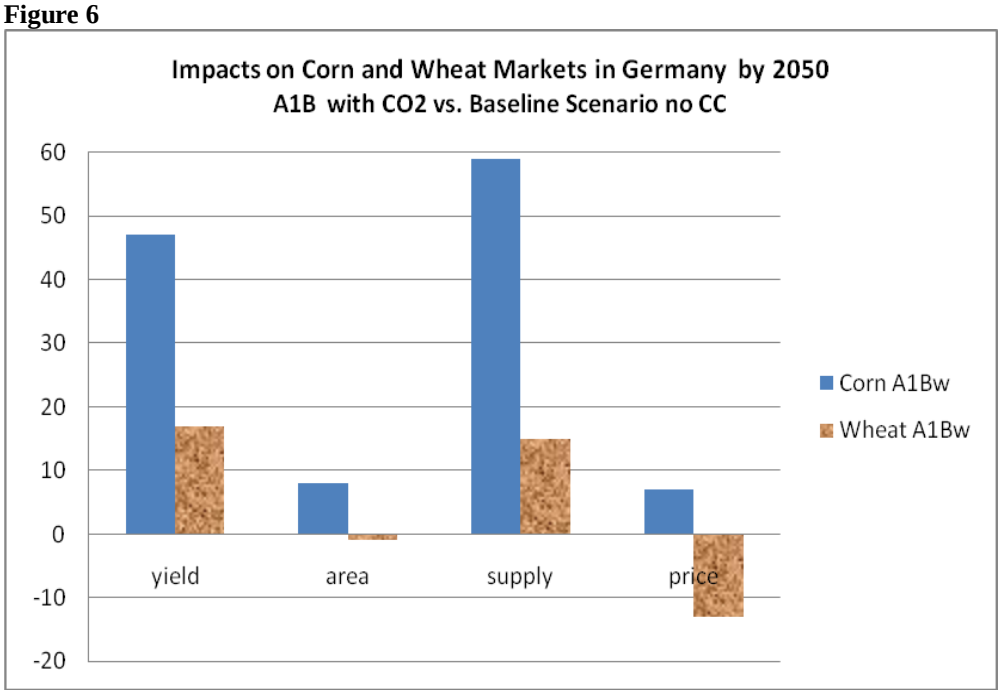
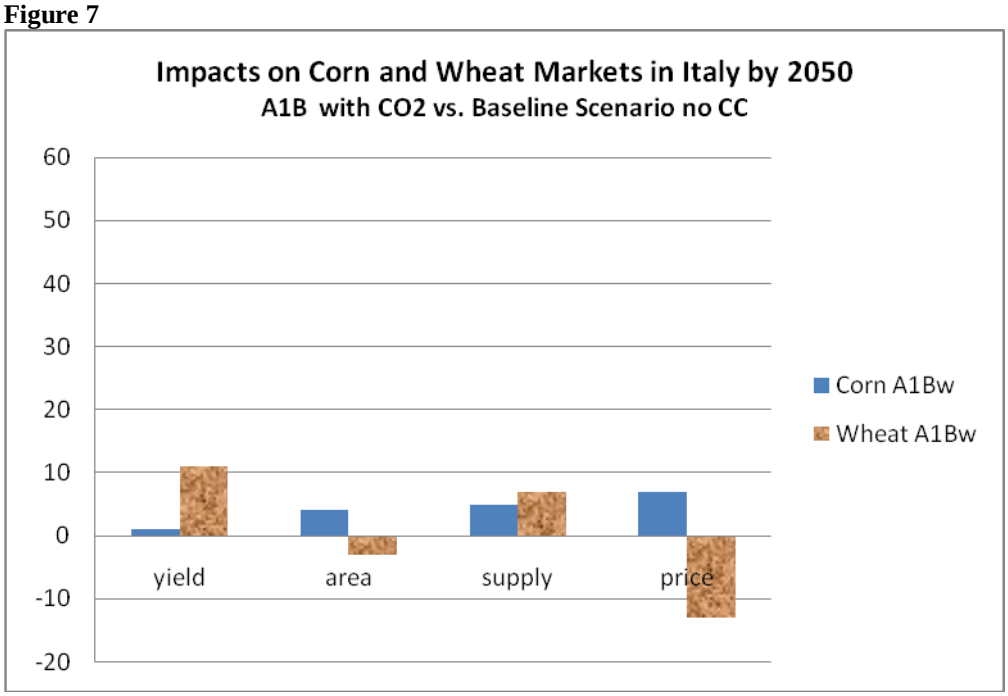


Figure 7


Impacts on Corn and Wheat Markets in Italy by 2050
A1B with CO2 vs. Baseline Scenario no CC
60
50
40
30
20
10
0
-10
-20
yield
area
supply
price
Corn A1Bw
Wheat A1Bw