The influence of climate change, technological progress and political change on agricultural land use: calculated scenarios for the Upper Danube catchment area

Einfluss von Klimawandel, technischem Fortschritt und politischen Änderungen auf die landwirtschaftliche Landnutzung: Szenarienberechnungen für das Flusseinzugsgebiet der Oberen Donau

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Abstract

Both climate and agricultural policy changes are commonly seen as important drivers for agricultural production. In this study, scenarios of climate and political change were calculated for the Upper Danube catchment area using the regional optimization model ACRE. Two political scenarios were calculated for the year 2020. One scenario assumes the continuation of the Common Agricultural Policy reform 2003 the other assumes a strong shift away from payments of the first pillar to payments of the second pillar of the CAP. Both scenarios were combined with four different scenarios of climate change and technological progress derived from ICCP SRES assumptions and the ACCELERATES project. The results of the scenario calculations were analysed with respect to their implications for the whole catchment area as well as for selected districts.

Climate change and technological progress both cause small changes in agricultural land use: fodder crop area tends to be converted to cash crop area, and intensive grasslands tend to be converted into extensive grasslands. Climate change and technological progress increase crop productivity, and consequently, total gross margin increases. The impact of climate change might get stronger toward the end of the century which is beyond the scope of the investigations presented here. The impact of climate change might thus switch from bringing net benefits in the short to medium term to bringing net losses for the area investigated in the long run.

Keywords

global change; regional model; climate change; agricultural policy scenarios; agricultural land use

Zusammenfassung

Änderungen des Klimas und der sozioökonomische Konditionen gelten als wichtige Einflussfaktoren für die landwirtschaftliche Produktion. In dieser Studie wurden mit dem regionalen Optimierungsmodel ACRE Szenarien unter Annahme klimatischer und politischer Änderungen für das Obere-Donau-Flusseinzugsgebiet berechnet. Es wurden für das Zieljahr 2020 zwei sozioökonomische Szenarien berechnet: Das eine Szenario simuliert die Fortführung der Gemeinsamen Agrarpolitik Reform 2003, das andere Szenario unterstellt eine extreme Umschichtung der Zahlungsmittel von der ersten Säule in die zweiten Säule der Gemeinsamen Agrarpolitik. Beide Szenarien wurden mit vier Szenarien des Klimawandels und des technischen Fortschritts kombiniert, welche aus Annahmen der IPCC SRES und dem Project ACCELERATES hergeleitet worden sind. Die Ergebnisse der Szenarienrechnungen wurden für das Gesamtgebiet sowie für ausgewählte Regionen analytisiert.

Sowohl Klimawandel als auch technischer Fortschritt haben geringe Auswirkungen auf die landwirtschaftliche Landnutzung. Tendenziell wird Ackerfutterfläche zu Marktfruchtfläche umgewidmet und intensives Grünland wird extensiviert. Klimawandel und technischer Fortschritt bewirken einen Anstieg der pflanzlichen Erträge und haben eine Erhöhung des Gesamtdeckungsbeitrags zur Folge. Die Auswirkungen des Klimawandels werden nach Ende der Untersuchungsperiode dieser Studie gegen Ende des 21. Jahrhunderts zunehmen. Dies könnte dazu führen, dass sich die positiven Auswirkungen, die diese Untersuchung kurz- bis mittelfristig gefunden hat, in ihr Gegenteil verkehren.

Schlüsselwörter

globaler Wandel; Regionalmodel; Klimawandel; agrarpolitische Szenarien; Landnutzung

1. Introduction

Mean temperature in Europe is expected to increase by 2.1 to 5.3°C over the remainder of this century (IPCC, 2007). Also, the occurrence of extreme weather events such as droughts or excess rain is expected to increase. No doubt, such climate change will cause changes in agricultural land-use. However, climate-induced changes in agricultural land use are strongly dependent on socioeconomic changes and feedback loops between agricultural land use and its drivers (ZEBISCH et al., 2005; FANGMEIER and FRANZARING, 2006; FORMAYER et al., 2001).

Recent studies of the impacts on agricultural land use tend to focus either on the consequences of economic and policy conditions or on climate change (see review in BUSCH, 2006). Only a few studies explicitly consider both socio-economic and climate change factors. However, current "Health Check" discussions on the further development and adjustments of the Common Agricultural Policy (CAP) in Europe address not only socioeconomic aspects, but also the question of how to master new challenges such as climate change (COM, 2007).

Table 1 provides a brief overview of some of the major projects addressing both socioeconomic and climate change factors in their scenario calculations. These projects differ in several respects: thematic focus, base year, time horizon,

Table 1. Climate and socioeconomic parameters driving agricultural land use in selected global change impact studies differing in their level of detail

Project	ACCELER-ATES	ATEAM	EURuralis	GLOWA-Elbe	RIVER-TWIN-Neckar	GLOWA-Danube
Time horizon	2080	2080	2030	2020	2030	2100
Time Step (in years)	30	30	10	-	10	1
Climate						
IPCC SRES[a)]	A1,A2,B1,B2	A1,A2,B1,B2	A1,A2,B1,B2	A1,B2	A2, B2	B2
GCM[b)]	HadCM3**	HadCM3**		ECHAM4**	ECHAM4	
Yield changes						
Crop yield model[c)]	ROIMPEL	-****	-*****	EPIC	EPIC	Biological
Regional scale	NUTS2	NUTS2	NUTS1	NUTS3	NUTS3	1 x 1 km
Defined crops	10	4	5	19	19	6
Socioeconomics						
Scenarios[d)]	WM,RE,GS,LS	A1,A2,B1,B2	GE,CG,GC,RC	PL,NT,CC	CAP reform	CAP reform
Policies	Set	Set	Set	Set	Energy crop	-
Prices	Set	Set	Modelled	Modelled	-	-
Techn. Progress	Set	Set	Set	Static	Static	-

[a)] IPCC Special Report on Emission Scenarios (SRES) (NAKIĆENOVIĆ et al., 2000): A1 (Global economic world), A2 (Regional economic world), B1 (Global environmental world), B2 (Regional environmental world). [b)] CGM: atmosphere-ocean general circulation models, *plus CGMCM2, CSIRO2, and PCM2 for the A2 storyline; **plus OPYC3; [c)] ROIMPEL: (MAYR et al., 1996); ***exogenously calculated productivity of wheat as proxy for food crops, ****endogenously calculated productivity by GTAP (technical progress), EPIC: Erosion Productivity Impact Calculator (WILLIAMS, 1984), Biological (LENZ et al., 2006). [d)] WM (World Markets), RE (Regional Enterprises), GS (Global Sustainability), and LS (Local Stewardship); GE (Global Economy), Continental Markets (CG), Global Co-Operation (GC), Regional Communities (GC); Partial Liberalisation (PL), Nitrogen Tax (NT), Climate Change (CC).

Source: authors' analysis

scenario design, geographical study area, spatial scale and techniques for modelling land use changes. The selected studies differ not only in their modelling approach, but also in their capability to translate qualitative storylines into quantitative input for modelling changes in land use (VERBURG et al., 2006). Furthermore, scenario parameters in these studies differ in their spatial resolution and in the level of detail in their representations. For example, the ACCELERATES study addresses socioeconomic parameters such as changes in policies, producer prices, and technological progress in great detail and over a particularly long projection period. In GLOWA-Elbe and EURuralis, in contrast, these parameters are considered over a medium-term time horizon, whereas SEAMLESS uses the most complex approach to quantify socioeconomic parameters, but only with a short-term horizon. GLOWA-Elbe and RIVERTWIN-Neckar make medium-term projections of climate-induced changes in agricultural yield, whereas ACCELERATES and ATEAM offer a long-term projection with a reasonable level of detail. In SEAMLESS, climate change scenarios are intended to be implemented at a later stage.

Most of the current impact studies predict rather small impacts of climate change in Germany over the next 10-20 years, and some studies predict that the impacts will continue to be small beyond this time frame. Most of them conclude that other factors, such as technological progress and the development of agricultural markets or agricultural policy, will be more important in the development of agricultural land use.

The aim of the study reported here was to investigate the effects of climate change, changes in agricultural policy, and technological progress on agricultural land use and profitability in the Upper Danube catchment up to the year 2020. Agricultural policy was simulated in order to take some trends and elements of the "Health Check" proposals in the broadest sense into account. Our key question was whether short- to medium-term policy analyses need to take into account climate change.

The following chapter briefly introduces the study area and the regional model ACRE, which was used for the scenario calculations, and it also discusses the assumptions behind the scenarios. Then, results for the complete model region and for selected districts are analysed and discussed.

2. The study area and the regional model ACRE

The river Danube has an overall length of 2 850 km with a total catchment area of 817 000 km². The Upper Danube basin, representing the research area of the project GLOWA-Danube (Global Change in the Hydrological Cycle), covers an area of 77 000 km² at its lowest point at Passau, and extends over five countries, primarily Germany and Austria. Germany has the largest portion, with a catchment area of 56 000 km² in Baden-Wuerttemberg and Bavaria, followed by Austria (Oberösterreich) with approximately 20 000 km². Approximately 55% of the catchment area is used for agricultural purposes (MAUSER and LUDWIG, 2002). Thus, studies of the effects of global changes on agricultural land use are of great interest for policy makers and other stakeholders in this region.

To calculate these impacts, the "Agro-eConomic pRoduction model at rEgional-level" (ACRE) was used. The model was developed within the GLOWA-Danube[1] project as a

[1] The project GLOW-Danube (URL: http://www.glowa-danube.de) is funded by the Federal Ministry of Education and Research (BMBF).

Table 2. Assumptions for the agricultural policy scenarios of the final status of CAP reform 2003 (CAP) and of the modulation scenario (MOD) in the year 2020

	Final status of CAP reform 2003 (CAP)	Modulation scenario (MOD)
Decoupled payments for UAA	regional payment entitlements (PE^{CAP}) + coupled aids	$PE^{MOD} = PE^{CAP} * 55\%$
Coupled aids	crop specific aids, e.g. for protein crops	cancelled
Environmental programs	payments for regional measures (ENV^{CAP})	$ENV^{MOD} = ENV^{CAP} + W * (PE^{CAP} * 45\%)$
Set-aside	obligatory regional quota	cancelled
Cross-Compliance	obligatory	obligatory
Producer prices	average prices in 2006 and 2007	average prices in 2006 and 2007
Milk quota	milk amount in calibration year	milk amount in calibration year
Market restrictions	yield of root crops in calibration year	yield of root crops in calibration year

W: Weighting factor according to the size of payments for the measures, according to MEKA (Marktentlastungs- und Kulturlandschaftsausgleich) in Baden-Wuerttemberg and KULAP (Kulturlandschaftsprogramm) in Bavaria.

According to $W_{measure\ X} = ENV^{CAP}_{measure\ X} * \left(\sum_{meaure\ N}^{measure\ 1} ENV^{CAP}_{measure} \right)^{-1}$ and $\sum_{measure\ N}^{measure\ 1} W_{measure} = 1$

Source: authors' compilation

tool to simulate the impacts of changes in climate and socioeconomic conditions on farming. The modelled region includes 74 districts (NUTS3 level[2]), 16 of which are located in Austria. However, the present study was carried out only for the part of the catchment lying within Germany.

ACRE is a comparative static optimization model that maximizes total gross margin by calculating the optimal combination of production activities for each NUTS3 district. Production factors of each district are aggregated, and farming in each district is represented by a single farm (the regional farm approach). The shortest simulation period was one year. ACRE has been calibrated with statistical data for the reference year 1995. The Positive Mathematical Programming (PMP) approach in ACRE was first published by HOWITT (1995) and extended by RÖHM and DABBERT (2003). The extended version distinguishes between main activities (e.g. crop activities) and variant activities (e.g. crop production intensities). Therefore, in the optimization process, ACRE considers two types of production variant activities (intensive variant activities and extensive variant activities). Overall, agricultural production includes 24 food and non-food crops and 15 production processes for livestock. Production of energy crops is not included.

ACRE is based on a process analytical approach; either cash crops or fodder crops for livestock production can be produced. The animals produce manure, which is used as fertilizer in crop production. Mineral fertilizer and feed concentrates can be purchased. Trade activities between the districts are not defined. Further details of ACRE-Danube are published in WINTER (2005) and HENSELER et al. (2006).

3. Scenario development

Scenario planning allows the identification of a range of possible futures and estimation of the consequences of possible interventions. Each scenario should be based on a logically consistent, internally coherent and plausible set of assumptions (MEADOWS et al., 2004; IPCC, 1994). Theoretically, the scenario space contains an infinite number of scenarios, from which only a few are typically considered.

In this study, two agricultural policy scenarios were established up to the year 2020. The baseline scenario assumes a continuation of CAP reform 2003. In the other scenario, a strong shift away from payments of the first pillar to payments of the second pillar of CAP (modulation) is assumed, implying a reduction of decoupled payment entitlements.

As climate scenarios, two scenarios from the family of scenarios of the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (IPPC SRES) were chosen: story line A1 and story line B2. Technological progress in this study is simulated by scenarios of the interdisciplinary project ACCELERATES (see table 1). We selected the globally oriented "World Market scenario" (WM), which assumes high technological progress, and the environmental friendly, sustainable scenario "Local Stewardship" (LS).

3.1 Agricultural policy scenarios

Two different agricultural policy scenarios were selected: (1) the "CAP" scenario, which extends the conditions of the final status of the 2003 CAP reform to the year 2020; and (2) the "MOD" scenario with extreme modulation, in which the payments of the first pillar of the CAP are reduced and partially shifted into the second pillar in the year 2020.

Table 2 summarizes the assumptions of both scenarios. In the CAP scenario, the first pillar of the CAP is modelled by decoupled payment entitlements, which are regionally differentiated for each hectare of utilized agricultural area (UAA). Some crops are associated with coupled aids, such as protein crops. The second pillar is modelled by payments for measures being promoted by environmental programs, which are defined for intensive grassland production, extensive grassland production, and intercropping on arable land. An obligatory regional set-aside quota and selected obligatory measures of Cross Compliance are modelled according to BMVEL (2005). Producer prices are assumed to increase due to a suggested scarcity of agricultural area and an increased demand for agricultural products on the world market. Therefore, the average prices of the last two years (2006 and 2007) are selected according to VTI (2008). Changes in milk quotas and in the sugar market are not considered in this study.

In the MOD scenario, the assumptions for cross compliance, producer prices, and market restrictions are the same

[2] Nomenclature of Territorial Units for Statistics (NUTS)

as in the CAP scenario. Obligatory set-aside is assumed to be cancelled due to the increased demand for the production factor farmland, resulting from area competition between food, fodder crops, and renewable resources. Moreover, the coupled aids are assumed to be abolished.

By modifying the subsidy regime in the MOD scenario, we tried to represent conditions in line with developments we think are likely. The modified subsidy regime we devised should reflect the following trends in agricultural policy: (1) a shift of money for payments from the first pillar to the second pillar, (2) a reduction of total expenditures for agricultural policy through a reduction of the total payments and (3) no change in the relative importance of the different environmental measures of the second pillar. In order to reach this the payments of the first pillar are modified: the regional payment entitlements are reduced to 45%. The amount subtracted is partially attributed to payments for the modelled measures of the regional environmental programs. The share of payments to the measures reflects a weighting of the original payment of environmental programs. This means, for example, that the first pillar payment for one hectare of UAA (PE^{CAP}) is reduced to 45%. The monetary amount of 55% that is thereby made available is not fully redistributed to the modelled measures of environmental programs. Instead, a weighted share of 55% is used for this purpose. Thus, the total volume of the subsidies is reduced.

Table 3 presents the calculation of regional payments for districts in Baden-Wuerttemberg and Bavaria for the three modelled environmental program measures, which are defined for intensive grassland, extensive grassland, and intercropping.

For example in Baden-Wuerttemberg, intensive grassland receives from the first CAP pillar 302 EUR ha^{-1} and from the second pillar 90 EUR ha^{-1}, resulting in a total of 392 EUR ha^{-1}. In MOD, the payments of the first pillar are reduced to 45%, which is 136 EUR ha^{-1}. This set free money of 166 EUR ha^{-1} (represented in table 2 by MOD minus CAP, or -166 EUR ha^{-1}). This money is redistributed partially to the second pillar payment for environmental programs. The weight of the environmental program is defined as 27%, according to the second pillar payments of 90 EUR ha^{-1}, which are 27% of the sum of payments for all payments for environmental measures (90 EUR ha^{-1} for intensive grassland + 130 EUR ha^{-1} for extensive grassland + 110 EUR ha^{-1} for intercropping = 330 EUR ha^{-1}). The amount of 45 EUR ha^{-1} is added to the original 90 EUR ha^{-1}. The resulting total of the first and second pillar in the MOD scenario is 271 EUR ha^{-1}, which is smaller by 121 EUR ha^{-1} (or 30%) than the CAP payments of 392 EUR ha^{-1}.

The MOD scenario thus implements the political goal of reducing the payments of the first pillar and increasing the payments of the second pillar. The assumed reduction of first pillar payment entitlements by 55%, in combination with only a partial redistribution of the money saved from the first pillar via environmental programs, results in a clear reduction of public expenditures.

3.2 Climate change scenarios

ACRE does not include climate parameters, but is driven (among other factors) by climate-induced changes in yield. Therefore, in order to simulate climate change impacts, crop-specific and spatially explicit calculations of yield on

Table 3. Calculation of payments [a] of the first and second pillar in CAP and MOD scenarios for the three measures of the environmental program in Baden-Wuerttemberg and Bavaria

Payments	Weight of measure *W* [b]	CAP	Transferred from 1st to 2nd pillar	MOD	Difference MOD – CAP
	EUR ha^{-1} or %				EUR ha^{-1}
Baden-Wuerttemberg [b]					
Intensive grassland					
1st pillar		302		45% * 302 = 136	136 – 302 = –166
2nd pillar	27%	90	27% * 166 = 45	90 + 45 = 135	135 – 90 = 45
Total		392		271	271 – 392 = –121
Extensive grassland					
1st pillar		302		45% * 302 = 136	136 – 302 = –166
2nd pillar	40%	130	40% * 166 = 66	130 + 66 = 196	196 – 130 = 66
Total		432		332	332 – 432 = –100
Intercropping					
1st pillar		302		45% * 302 = 136	136 – 302 = –166
2nd pillar	33%	110	33% * 166 = 55	110 + 55 = 165	165 – 110 = 55
Total		412		301	301 – 412 = –111
Bavaria [b]					
Intensive grassland					
1st pillar		340		45% * 340 = 153	153 – 340 = –187
2nd pillar	20%	50	20% * 187 = 37	50 + 37 = 87	87 – 50 = 37
Total		390		240	240 – 390 = –150
Extensive grassland					
1st pillar		340		45% * 340 = 153	153 – 340 = –187
2nd pillar	42%	100	42% * 187 = 78	100 + 78 = 178	178 – 100 = 78
Total		440		331	331 – 440 = –109
Intercropping					
1st pillar		340		45% * 340 = 153	153 – 340 = –187
2nd pillar	38%	90	38% * 187 = 70	90 + 70 = 160	160 – 90 = 70
Total		430		313	313 – 430 = –117

[a] Small deviations are caused by rounding errors.
[b] Weight *W* is the payment for the measures weighted by the sum of payments for all measures.
Source: authors' calculations

Table 4. Description of Special Report on Emission Scenarios (SRES)

Story line A1	Story line B2
Orientation of future development: economic-global	**Orientation of future development: environmental-regional**
Economic development • very rapid economic growth • global population peaks in mid-century and declines thereafter • rapid introduction of new and more efficient technologies • emphasis on substantial reduction in regional differences in per capita income High temperature increase	Economic development • intermediate levels of economic development • continuously increasing global population, at a rate lower than A1 • less rapid and more diverse technological change than in B1 and A1 • emphasis on local solutions to economic, social and environmental sustainability Moderate temperature increase

Source: authors' compilation

NUTS2 level from the crop yield model ROIMPEL (AUDSLEY et al., 2006) were used. These calculations were based on HadCM3 climate projections (MITCHELL et al., 2004) for each scenario of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (IPCC SRES). From the IPCC scenario family, the storylines A1 and B2 were chosen, which are described in table 4. Story line A1 shows a higher temperature increase in comparison to story line B2, which is of moderate temperature increase.

ROIMPEL is an agro-climatic simulation model of crop yields using soil/terrain information, such as soil texture and organic matter, as well as weather/climate variables, such as monthly values of average daily temperature and monthly cumulative precipitation (MAYR et al., 1996). The model ROIMPEL predicts crop yields limited by soil water and nitrogen availability and simulates sowing dates, maturity days, number of workable days, and nitrate concentrations. The model also includes elaborate algorithms for computing dynamics of water budget elements (e.g. evaporation, transpiration, drainage), dynamics of leaf area index (LAI) as related to crop development, and sowing dates.

Potential daily accumulation of biomass is based on the net photosynthetically active radiation and the radiation use efficiency, with the efficiency being CO_2 concentrate sensitive. Potential daily increase of biomass is corrected by water, temperature, or nitrogen stress and additional penalties (e.g. unfavourable weather during critical development stages).

ROIMPEL was validated against data from Bulgaria and the Czech Republic, and it performed adequately compared to the CERES (model details are described elsewhere; see AUDSLEY et al., 2006).

ROIMPEL calculated the yield development at the NUTS2 level for eight different crops and grasslands. ROIMPEL data imply that the influence of climate and elevated CO_2 in the Upper Danube catchment is projected to be small in both IPCC storylines (A1 and B2) over the next decade for major crops; for example, yield increases of cereals and grassland are estimated to be +6% to +14% relative to the base yield (table 5). Silage maize, corresponding to the principal fodder crop, shows a significant change (from -11% to +51% relative to base yield), which appears to be plausible due to its C4 carbon fixation pathway. The C4 metabolism gives maize a competitive advantage over C3 plants under conditions of drought and high temperatures and at the same time makes it more vulnerable to unfavourable climatic conditions. Changes in precipitation due to climate change are modelled by the soil water supply and are therefore included in the changes in crop yield.

The results for the eight different crops plus grassland and 12 NUTS2 regions were allocated for each crop and model district, respectively, and used as input for ACRE.

3.3 Scenarios of technological progress

Simulated technological progress in agriculture concern future improvements in crop production resulting from progress in breeding and crop management and are represented by increases in crop yields.

Yields of major crops in Europe have steadily increased during the past 50 years (EWERT et al., 2005; HAFNER, 2003). In Germany, agricultural yields have more than tripled since 1950 (STERZEL, 2004; FRANZARING et al., 2006). This development was largely driven by technological progress in agriculture, and in particular by progress in

Table 5. Changes in crop yield of selected crops for the scenario in story lines A1 and B2 in the year 2020

NUTS2 regions [d]	IPPC story line A1			IPPC story line B2		
	Cereals [a]	Fodder crops [b]	Grass-land [c]	Cereals [a]	Fodder crops [b]	Grass-land [c]
Stuttgart	108	123	105	108	127	105
Freiburg	106	124	107	106	128	107
Tübingen	107	151	102	107	157	104
Oberbayern	109	89	113	111	91	114
Niederbayern	109	124	113	109	127	112
Oberpfalz	109	118	113	112	125	114
Mittelfranken	112	141	110	112	145	112
Schwaben	106	142	107	108	143	107

[a] Changes in cereal yields are represented here by the change in yield of the most relevant cereal crops in each region, such as winter wheat. [b] Yield changes of fodder crops are represented here by the crop yield change of the regionally most relevant cereal crops, such as silage maize. [c] Yield changes of grassland are representative for intensive and extensive grasslands. Source: SIMOTA (2007), authors' calculations; [d] NUTS2 regions (dt. Regierungsbezirke) including NUTS3 districts of the German Upper Danube Catchment area. Note: nitrogen availability is assumed to be non-limiting in the calculation of crop yields.

Source: authors' calculations based on SIMOTA (2007) breeding (e.g. selection of higher-yield genotypes and disease or stress resistance), together with progress in crop management associated with fertilization, pest and weed control, tillage, water use, and improved machinery (EWERT et al., 2005; FRANZARING et al., 2006). Similarly, future productivity increases are likely to be driven by technological progress (EWERT et al., 2005; HAFNER, 2003).

The projected effects of technological change were drawn from expert judgements based on historical changes in agricultural productivity (EWERT et al., 2005) within the ACCELERATES project (ABILDTRUP et al., 2006). To simulate changes in yield due to agricultural technological progress, two scenarios were selected. Four scenarios are defined in the ACCELERATES project, and they correspond to the four different storylines of IPCC emission scenarios: a more economic- and global-oriented future in the "World Market scenario" (WM); a more environmental and regional future under the "Local Stewardship" (LS) scenario; and intermediate scenarios with an economic regional orientation and an environmental global orientation under the "Regional Enterprises" (RE) and "Global Sustainability" (GS) scenarios, respectively. The scenarios equivalent to the selected ICCP story lines A1 and B2 were used in this study: World Market scenario (WM) and the Local Stewardship scenario (LS).

The assumed changes in yield due to technological progress show a distinct gradient, ranging from large changes in the WM scenario to insignificant changes in the LS scenario (table 6). No estimates for grassland were made in ACCELERATES, so the effect of technological progress on grassland yield was assumed to be the same as the average effect on crops.[3]

Table 6. Crop and grassland yield changes under different scenarios of socioeconomic change (ABILDTRUP et al., 2006: 111) due to technological progress in 2020 (percentage relative to base yield)

	2000	2020			
		World Market (WM)		Local Stewardship (LS)	
		Crop	Grass	Crop	Grass
	%	%		%	
Yield change due to technological progress	100	167	167	104	104
Corresponding IPCC SRES story line		A1		B2	

Source: based on ABILDTRUP et al. (2006)

3.4 Combined agricultural policy and climate scenarios

For the scenario calculations in this study, the two socioeconomic scenarios were combined with the scenarios of climate change and technological progress for the year 2020. In order to observe the influence of politics, climate, and technology separately, the drivers were partially combined in 10 scenarios.

[3] The percentage values of technological progress in this study were taken directly from the project ACCELERATES. They certainly represent extreme scenarios. A more likely development might be between these two scenarios.

4. Results of global change scenario calculations with ACRE

The results of the 10 developed scenarios were analyzed for the complete model region on the one hand and for selected districts on the other. The parameters investigated were changes in agricultural land use, in total gross margin (TGM) and in subsidies (SUB). The land use classes used to represent changes in arable land were cereals, as the most important cash crop, fodder crops, and set-aside. Regarding grassland, intensively and extensively used grassland, as well as abandoned grassland were examined. To analyze possible changes, the scenario results were compared with the baseline scenario (CAP).

4.1 Results for the complete model region

Table 7 presents the results of the scenario calculations for the complete model region (MR).

In comparison to the CAP scenario, the area of cereals crops increased by 4% of UAA (4 percentage points) and the area of fodder crops rose by 1% of UAA in the modulation scenario (MOD) assuming no climate change or technological progress. This increase resulted from set-aside area that became used for agricultural production because of the cancellation of the obligatory set-aside quota in MOD. Total gross margin decreased by 11% and the subsidy volume decreased by 40% because direct payments to the first pillar were only partially shifted onto the second pillar. According to the extensions of the environmental measures the subsidies in the districts decrease in a range of 20-50%.

The results for a climate change scenario with high temperature increases (A1) show that under CAP reform conditions, the area of cereals increased by 2 percentage points and fodder crops decreased by 2 percentage points. Climate change increased the yields of fodder crops and hence the productivity of the fodder crop area. In this scenario, then, less fodder crop area is required to produce the demanded amount of fodder. The fodder area liberated can then be used for cash crop production. Due to the increase in productivity of the extensive grassland area, grassland production shifted slightly from intensive to extensive production. The increase in crop yields in scenario CAP-A1 led to a 6% increase in TGM.

In the modulation scenario with the climate change described in the A1 story line (MOD-A1) the area set aside was reduced by 4 percentage points to zero because of the cancellation of the obligatory set-aside. This increased the cereals area by 6 percentage points. A small shift in grassland usage could be detected. Total gross margin decreased by only 5%, although the volume of subsidies decreased by 40%. The influence of climate change can be seen by comparing the change in total gross margin (TGM) in the MOD scenario. Without the influence of the high temperature increase scenario, the total gross margin decreased by 11%, although the volume of subsidies was reduced by the same amount to 60%. In this way, the increase in crop yields due to climate change partially compensated the loss of income.

Table 7. Development of land use, total gross margin (TGM), and subsidy volume (SUB) for the complete model region (MR) in the calculated scenarios in comparison with the baseline scenario that assumes continuation of CAP reform 2003 (CAP) in 2020

Scenario	Cereals	Fodder crops a)	Others b)	Set-side	Int. GL c)	Ext. GL d)	Aband. GL e)	TGM f)	SUB g)
	Percentage difference to CAP in % of UAA h)							% of CAP i)	
CAP i)	0	0	0	0	0	0	0	100	100
MOD j)	4	1	0	-5	0	0	0	89	60
CAP-A1 k)	2	-2	0	0	-1	1	0	106	100
MOD-A1 l)	6	-2	0	-4	-2	2	0	95	60
CAP-B2 m)	2	-2	0	0	-1	1	0	106	100
MOD-B2 n)	6	-2	1	-5	-2	2	0	95	60
CAP-A1WM o)	10	-9	-1	0	-6	5	0	129	99
MOD-A1WM p)	14	-8	-1	-5	-6	5	1	119	59
CAP-B2LS q)	2	-3*	0	0	-2	2	0	108	100
MOD-B2LS r)	7	-2	0	-5	-2	2	0	97	60

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Average percentage difference between the corresponding scenario and baseline CAP scenario in % of utilized agricultural area (UAA). For the model region (MR) the values represent the values for the complete model region and do not represent the means. i) CAP: baseline scenario; according to the final status of the Common Agricultural Policy reform 2003, levels of TGM and SUB in CAP were taken to be 100%; j) MOD: modulation scenario; k) CAP-A1: CAP scenario combined with crop yield from climate change scenario A1. l) MOD-A1: modulation scenario combined with crop yield from climate change scenario A1. m) CAP-B2: CAP scenario with crop yield from climate change scenario B2. n) MOD-B2: modulation scenario combined with crop yield from climate change scenario B2. o) CAP-A1WM: CAP scenario with crop yield from climate change scenario A1 and technological progress from World Market scenario (WM). p) MOD-A1WM: modulation scenario with crop yield from climate change scenario A1 and technological progress from World Market scenario (WM). q) CAP-B2LS: CAP scenario with crop yield from climate change scenario B2 and technological progress from Local Stewardship scenario (LS). r) MOD-B2LS: modulation scenario with crop yield from climate change scenario B2 and technological progress from Local Stewardship scenario (LS). * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

The characteristics of scenarios with moderate increased temperature (CAP-B2 and MOD-B2) were quite similar to those of the scenarios CAP-A1 and MOD-A1. In fact, crop yield changes in both climate scenarios with high and moderate increased temperature were similar (see table 5). Therefore, the influence of climate change in the scenarios CAP-B2 and MOD-B2 was nearly the same as in CAP-A1 and MOD-A1.

In scenarios CAP-A1WM and MOD-A1WM, additionally the high technological progress of the ACCELERATES world market scenario (WM) was combined with the changes in crop yields in the high temperature increased scenario. This produced an extremely large increase in crop yield, and most of the increase was due to technological progress (see also table 6). The increase in fodder crop productivity meant that the fodder area could be reduced by 9% and 8% of UAA, respectively, leading to a concomitant increase in cereals area of 10% and 14% of UAA. Moreover, the shift from intensive to extensive grassland production was strongly affected by the large increase in grassland productivity. The increase in fodder crop yields decreased the fodder crop area required to meet demand in both scenarios CAP-A1WM and MOD-A1WM. Nevertheless, formerly set-aside area in MOD-A1WM was redistributed such that the area of cash and fodder crops increased by an additional 5% of UAA.

The large increases in crop productivity raised the TGM by 29% in CAP-A1WM and by 19% in MOD-A1WM. Without climate change and technological progress, the modulation scenario resulted in a decreased TGM. Thus, both factors compensated the income losses of modulation.

The lower technological progress in the Local Stewardship scenario (LS) increased crop yields by only 4% (see table 6). Thus, the effect of technological advancement was very small and the changes in land use were similar in size to those scenarios with high temperature increase (CAP-A1 and MOD-A1). However, in the MOD scenario with moderate increased temperature and a lower technological progress (MOD-B2LS), changes in yield were high enough to let total gross margin decrease only slightly. The effects of climate change and technological progress are high enough to compensate nearly for the income losses caused by modulation.

4.2 Results for selected districts

4.2.1 Characteristics of the selected districts

In order to analyze the results of the simulated scenarios at the regional level, we selected 20 representative districts ranging from intensive arable land farming to extensive grassland farming. The districts were arable land districts with predominant cash crop production (CC), arable land districts with fodder crop production (FC), grassland districts with a high proportion of intensively used grassland (IG), and grassland districts with a high proportion of extensively used grassland (EG). In order to summarize the results, we clustered the districts and analysed the mean values of their reactions. The mean values of the characteristics of the complete model region (MR) and the selected districts are presented in table 8 for the baseline scenario of CAP reform 2003 (CAP). The figures illustrate that the average selected cash crop district (CC) is characterized by a small grassland share of 16% of UAA, and a high share of cash crop area (65% of UAA), resulting in a high average total gross margin (TGM) of approximately 1693 EUR ha^{-1}. Fodder crop (FC) districts differed from cash crop districts (CC) in the share of fodder crops and

Table 8. Characteristics of the model region (MR) and farm types in mean values in CAP scenario in 2020

	Total UAA a)	GL b)	Cereals	Fodder crops c)	Others d)	Set-aside	Int. GL e)	Ext. GL f)	TGM g)	SUB h)
	ha	% of UAA							EUR ha^{-1}	
MR i)	**52 939**	**42**	**33**	**14**	**6**	**5**	**16**	**26**	**1 470**	**405**
CC j,*)	51 406	16	47	13	18	7	5	11	1 693	354
FC k)	56 429	17	47	21	8	7	8	9	1 482	354
IG l)	74 542	82	8	8	1	1	37	45	1 645	433
EG m,*)	34 484	93	2	5	0	1	18	75	1 213	515

a) UAA: utilized agricultural area; b) GL: grassland; c) Fodder crops: including clover and silage maize; d) Others: other cash crops including oilseeds, legumes, root crops and special crops. e) Int. GL: Intensive grassland; f) Ext. GL: Extensive grassland; g) TGM: average total gross margin; h) SUB: average volume of subsidies; i) MR: model region; j) Cash crop districts; k) FC: Fodder crop districts; l) IG: Intensive grassland; m) EG: Extensive grassland.* Calculation of mean values and rounding errors result in a sum unequal to 100% in this farm type.

Source: authors' calculations

was subsequently taken over for cereal crop production. This takeover was made possible by the cancellation of the requirement to set aside about 9% of arable area. In both grassland districts (IG and EG), land use changed only slightly through a small reduction in set-aside area and an increase in cereals and fodder crops areas. other cash crops (others). They also had smaller average total gross margins and similar average subsidies.

Table 9 shows the changes of land use, total gross margin, and subsidies for the district types and the model region (MR) in the CAP reform 2003 scenario and modulation scenario (MOD). The CAP scenario is the baseline scenario and is used as the reference for calculating differences. Thus, comparing the CAP scenario with itself results in zero changes in land use and 100% change in comparison with TGM and SUB.

In the modulation scenario (MOD), significant increases in cereals area and decreases in set-aside area were observed. These changes were largest in cash crop districts (CC) and in fodder crop districts (FC). These results were due to the greater proportion of area that was originally set aside in the arable land districts (approximately 7% of UAA) and that

All district types reduced their TGM by approximately 10% as a result of modulated and reduced subsidies. The effect of eliminating the set-aside requirement on total gross margin was relatively weak, increasing it by only 1-2% in arable districts (CC and FC) and by a maximum of 3-4% in grassland districts.

In CC and FC arable land districts, subsidy volume decreased more than in IG and EG grassland districts. Due to the small proportion of grassland in arable land districts, the modulated money was distributed to only a few hectares with environmental programs for grassland. Environmental programs stipulated fewer payments for measures on arable land than on grassland farming. Thus, as could be expected, grassland districts received more modulated money for more grassland hectares than did arable land districts.

Table 9. Development of land use, volume of total gross margin (TGM), and volume of subsidies (SUB) for the complete model region (MR) and the four district types in scenarios CAP and MOD in 2020

Scenario		Cereals	Fodder crops a)	Others b)	Set-side	Int. GL c)	Ext. GL d)	Aband. GL e)	TGM f)	SUB g)
		Means of percentage difference from CAP in % of UAA h)							% of CAP h)	
CAP i)	**MR k)**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**100**	**100**
	CC l)	0	0	0	0	0	0	0	100	100
	FC m)	0	0	0	0	0	0	0	100	100
	IG n)	0	0	0	0	0	0	0	100	100
	EG o)	0	0	0	0	0	0	0	100	100
MOD j)	**MR k)**	**4**	**1**	**0**	**-5**	**0**	**0**	**0**	**89**	**60**
	CC l)	6	1	0	-7	0	0	0	89	49
	FC m)	6	1	0	-7	0	0	0	88	49
	IG n)	1*	1*	0	-1*	0	0	0	91	66
	EG o)	0	1	0	-1	0	0	0	89	74

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops, and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Development of land use is represented by the means of the percentage difference between the corresponding scenario and the CAP baseline scenario in % of utilized agricultural area (UAA). Development of TGM and SUB is represented by percentage changes with TGM and SUB in CAP defined as 100%. For the model region (MR), the values represent the values for the complete model region and do not represent the means. i) CAP: baseline scenario according to the final status of the Common Agricultural Policy reform 2003; j) MOD: modulation scenario; k) MR: model region; l) Cash crop districts; m) FC: Fodder crop districts; n) IG: Intensive grassland; o) EG: Extensive grassland; * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

Table 10 presents the results for the districts and the model region (MR) for climate change scenario with high temperature increase (A1). In scenario CAP-A1, fodder crop area in CC and FC arable districts decreased by 2% and 4% of UAA due to increased crop productivity. The resulting enlarged production area and the increased productivity of cereals caused the total gross margin (TGM) to increase by 8%.

In IG and EG grassland districts, the grassland shifted from intensive to extensive grassland. This change in land use resulted in a slight increase in TGM (2%).

In modulated scenarios involving the high temperature increase (MOD-A1), the increase in utilized agricultural area (UAA) due to formerly set-aside area and to fodder crop area led to an increase in cereals production. In IG and EG grassland districts, grassland changed from intensive to extensive usage by 4% and 3% of UAA, respectively.

In CC and FC arable land districts, the loss of TGM due to reduced subsidies was nearly compensated by increases in crop yields caused by climate change. TGM decreased by only 3-4% on average. In grassland districts, the loss of income was bigger and accumulated to 6-10%. Nevertheless, in IG grassland districts, the high temperature increasing climate change scenario (A1) limited the loss of agricultural income to 6% of TGM compared to the modulation scenario without climate change A1 (table 10). In MOD scenario, losses were 9% of TGM (table 9). The income of EG districts was not significantly affected by climate.

Table 11 presents the results in the districts for the climate change scenario with moderate temperature increase (B2). As observed for the model region, the scenarios CAP-B2 and MOD-B2 show changes similar to those in the scenarios CAP-A1 and MOD-A1 (table 11). The largest change occurred in fodder crops. The increase in fodder crop yield in B2 exceeded that in A1 by 3 to 4 percentage points in most of the regions. This explains why in MOD-B2, 1% percentage points more intensive grassland (5% of UAA) shifted to extensive cultivation compared to the shift of 4% of UAA in MOD-A1. Due to the higher fodder crop yield in B2, the higher productivity of fodder crop area reduced the requirement for fodder production from grassland, and grassland could be reduced in intensity. In CC and FC arable land districts, crop yield increases resulted in slightly higher total gross margins (TGM); TGM changes in cash crop districts in CAP-A1 were +8% and +9% in CAP-B2.

Table 12 presents the results in the districts for climate change scenario and technological progress scenario A1WM. Scenario A1WM combined the crop yield changes from climate scenario A1 and the crop yield changes from technological progress in the World Market (WM) scenario. Combining the political scenarios CAP and MOD with the changes in yield in A1WM produced the most extreme changes in all simulated scenarios.

In CAP-A1WM, the cereals area increased by 14 percentage points in CC and FC arable land districts. This resulted from the large increase in fodder crop area productivity. Fodder area was reduced and the area liberated (9% of UAA in CC and 5% of UAA in FC) was converted to cereal production. In CC and FC arable land districts, total gross margin increased by 41% and 43%. In IG and EG grassland districts, the increase in cereal production and decrease in fodder crop area was between 2-4 percentage points of the lower UAA. The use of grassland shifted by 15 percentage points in IG districts and by 11 percentage points in EG districts from intensive to extensive, respectively and 1% of UAA in EG was abandoned. These drastic changes were the result of the large increases in fodder crop production and grassland yield. However, in IG and EG districts, total gross margin increased by only 9% and 5% because of the smaller cash crop area.

Table 10. Development of land use, volume of total gross margin (TGM), and volume of subsidies (SUB) for the complete model region (MR) and the four district types in scenarios CAP-A1 and MOD-A1

Scenario		Cereals	Fodder crops [a)]	Others [b)]	Set-side	Int. GL [c)]	Ext. GL [d)]	Aband. GL [e)]	TGM [f)]	SUB [g)]
		Means of percentage difference from CAP in % of UAA [h)]							% of CAP [h)]	
CAP-A1 [i)]	**MR [k)]**	**2**	**-2**	**0**	**0**	**-1**	**1**	**0**	**106**	**100**
	CC [l)]	2	-2	0	0	0	0	0	108	100
	FC [m)]	3	-4	1	0	-1	1	0	108	100
	IG [n)]	1	-1	0	0	-3	3	0	102	99
	EG [o)]	0	0	0	0	-2	2	0	102	99
MOD-A1 [j)]	**MR [k)]**	**6**	**-2**	**0**	**-5**	**-2**	**2**	**0**	**95**	**60**
	CC [l)]	8	-1	0	-7	0	0	0	97	49
	FC [m)]	9	-3	1	-7	-1	1	0	96	49
	IG [n)]	1	0	0	-1	-4	4	0	94	65
	EG [o)]	1	0	0	-1	-3	3	0	90	74

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops, and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Development of land use is represented by the means of the percentage difference between the corresponding scenario and the CAP baseline scenario in % of utilized agricultural area (UAA). Development of TGM and SUB is represented by percentage changes with TGM and SUB in CAP defined as 100%. For the model region (MR), the values represent the values for the complete model region and do not represent the means. i) CAP-A1: Common Agricultural Policy reform 2003 and climate change story line A1; j) MOD-A1: modulation scenario and climate change story line A1; k) MR: model region; l) Cash crop districts; m) FC: Fodder crop districts; n) IG: Intensive grassland; o) EG: Extensive grassland; * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

Table 11. Development of land use, volume of total gross margin (TGM), and volume of subsidies (SUB) for the complete model region (MR) and the four district types in scenarios CAP-B2 and MOD-B2

Scenario		Cereals	Fodder crops a)	Others b)	Set-side	Int. GL c)	Ext. GL d)	Aband. GL e)	TGM f)	SUB g)
		Means of percentage difference from CAP in % of UAA h)							% of CAP h)	
CAP-B2 i)	**MR k)**	**2**	**-2**	**0**	**0**	**-1**	**1**	**0**	**106**	**100**
	CC l)	2	-2	0	0	0	0	0	109	100
	FC m)	3*	-4*	1	0	-1*	1*	0	109	100
	IG n)	1	-1	0	0	-3	3	0	102	99
	EG o)	0	0	0	0	-2	2	0	102	99
MOD-B2 j)	**MR k)**	**6**	**-2**	**1**	**-5**	**-2**	**2**	**0**	**95**	**60**
	CC l)	8*	-2*	0	-7*	0	0	0	98	49
	FC m)	9	-3	1	-7	0	0	0	97	49
	IG n)	1	0	0	-1	-5	5	0	94	65
	EG o)	1	0	0	-1	-3	3	0	91	74

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops, and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Development of land use is represented by the means of the percentage difference between the corresponding scenario and the CAP baseline scenario in % of utilized agricultural area (UAA). Development of TGM and SUB is represented by percentage changes with TGM and SUB in CAP defined as 100%. For the model region (MR), the values represent the values for the complete model region and do not represent the means. i) CAP-B2: baseline scenario according to the final status of the Common Agricultural Policy reform 2003 and climate change story line B2; j) MOD-B2: modulation scenario and climate change story line B2; k) MR: model region; l) Cash crop districts; m) FC: Fodder crop districts; n) IG: Intensive grassland; o) EG: Extensive grassland; * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

In MOD-A1WM in CC districts, set-aside area, fodder crop area, and area for other cash crops decreased by 7%, 8%, and 5% of UAA. This area (20% of UAA) was used for cereal production. The increased cereal area and higher crop yields caused an increase in total gross margin of about 31%, 10% less than in CAP-A1WM. Similar results were observed for FC districts, which showed a larger decrease in fodder crop area (12% of UAA) and an even higher TGM increase of 33%. In grassland districts, grassland usage shifted significantly from intensive to extensive production by 17% of UAA in IG districts of and by 10% of UAA in EG districts. In EG districts grassland equivalent to 3% of UAA was abandoned.

Table 12. Development of land use, volume of total gross margin (TGM), and volume of subsidies (SUB) for the complete model region (MR) and the four district types in scenarios CAP-A1WM and MOD-A1WM

Scenario		Cereals	Fodder crops a)	Others b)	Set-side	Int. GL c)	Ext. GL d)	Aband. GL e)	TGM f)	SUB g)
		Means of percentage difference from CAP in % of UAA h)							% of CAP h)	
CAP-A1WM i)	**MR k)**	**10**	**-9**	**-1**	**0**	**-6***	**5***	**0**	**129**	**99**
	CC l)	14	-9	-5	0	0	0	0	141	100
	FC m)	14*	-12*	-1*	0	-1	1	0	143	100
	IG n)	4	-4	0	0	-15	15	0	109	95
	EG o)	2	-2	0	0	-11	10	1	105	96
MOD-A1WM j)	**MR k)**	**14**	**-8**	**-1**	**-5**	**-6**	**5**	**1**	**119**	**59**
	CC l)	20	-8	-5	-7	0	0	0	131	49
	FC m)	20	-12	-1	-7	-1	1	0	133	49
	IG n)	5	-4	0	-1	-17*	16*	0	102	65
	EG o)	2	-2	0	-1	-10	8	3	94	71

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops, and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Development of land use is represented by the means of the percentage difference between the corresponding scenario and the CAP baseline scenario in % of utilized agricultural area (UAA). Development of TGM and SUB is represented by percentage changes with TGM and SUB in CAP defined as 100%. For the model region (MR), the values represent the values for the complete model region and do not represent the means. i) CAP: baseline scenario according to the final status of the Common Agricultural Policy reform 2003 and climate change of story line A1 and technological progress of World Market scenario (WM); j) MOD: modulation scenario and climate change of story line A1 and technological progress of World Market scenario (WM); k) MR: model region; l) Cash crop districts; m) FC: Fodder crop districts; n) IG: Intensive grassland; o) EG: Extensive grassland; * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

The increases in yield caused by climate changes and technological progress compensated for the loss of total gross margin, due to subsidy reduction and modulation. With a subsidy volume in this scenario of just 70% compared to the CAP scenario, EG districts lost 6% of their income in MOD-A1WM. Thus, in EG districts, climate change and technological progress affected the total gross margin positively by limiting losses. Without the yield increases, total gross margin would have been reduced by 11% in MOD scenario (see table 9 and table 12).

Table 13 presents the results for the districts for the scenario B2LS, which combines the changes in crop yield from climate scenario B2 and from the technological progress in the Local Stewardship (LS) scenario.

While crop yield changes in the moderate temperature increase scenario (B2) were similar to those in the high temperature increase scenario (A1), crop yield changes due to technological progress in the LS scenario were quite small (4%, table 6).

The development of land use showed the same tendency as in the crop yield scenario A1WM, with increases in areas of cereals and extensive grassland and decreases in areas of fodder crops and intensive grassland. However, the changes were less extreme than in the case of A1WM, because the increase in crop yield due to technological progress was very small (4%).

In CAP-B2LS, crop yield increased and the extension of cereal area in arable land districts (e.g. +3% of UAA in CC) resulted in increases of total gross margin of 11%. Crop yields increased, and the slight increase in cereals area, together with shifts from intensive to extensive grassland, caused the TGM to increase by 2% and 3%, respectively, in IG and EG districts. Despite the extreme, 50% reduction of subsidies in the modulation scenario MOD-B2LS, the total gross margin in CC and FC arable land districts remained at approximately 100% due to the reduction in areas of fodder crops and set-aside land, as well as the increases in cash crop area and crop yields. In contrast, these changes and the conversion from intensive to extensive grassland in IG and EG districts decreased the TGM by a relatively small amount, namely 5% and 9%, respectively.

Obviously, even the more moderate increase in crop productivity due to technical progress in the MOD-B2LS scenario enables the farm types to maintain TGM or to suffer only small losses, even though the substantial 25-50% reduction in subsidies strongly reduces public expenditures. In this scenario, the smaller increase in fodder crops and grassland resulted in a positive effect. No grasslands were abandoned, indicating that management of the landscape was ensured by agriculture.

Climate change and technological progress resulted in a reduction in fodder area and an increase in cereals area in CC and FC arable land districts. In IG and EG districts, intensive grassland was converted to extensive grassland. Total gross margin increased in CC and FC arable districts more than in grassland districts (IG and EG). Technological progress had a greater impact in these scenarios than did climate change.

The modulation scenario resulted in a decrease of set-aside area, which was converted to a cash crop area. The volume of subsidies (SUB) decreased in CC and FC arable districts more than in IG and EG districts. Total gross margin decreased due to reduction of subsidies. However, climate change and technological progress compensated for the loss of income by increasing crop yields and cash crop production. In CC and FC arable land districts, the compensation for losses was greater than in grassland districts. Nevertheless, even in scenarios making less extreme assumptions,

Table 13. Development of land use, volume of total gross margin (TGM), and volume of subsidies (SUB) for the complete model region (MR) and the four district types in scenarios CAP-B2LS and MOD-B2LS

Scenario		Cereals	Fodder crops a)	Others b)	Set-side	Int. GL c)	Ext. GL d)	Aband. GL e)	TGM f)	SUB g)
		Means of percentage difference from CAP in % of UAA h)							% of CAP h)	
CAP-B2LS i)	**MR k)**	**2***	**-3***	**0**	**0**	**-2**	**2**	**0**	**108**	**100**
	CC l)	3*	-2*	0	0	0	0	0	111	101
	FC m)	4	-5	1	0	-1	1	0	111	100
	IG n)	1	-1	0	0	-4	4	0	103	99
	EG o)	0	0	0	0	-3	3	0	102	99
MOD-B2LS j)	**MR k)**	**7**	**-2**	**0**	**-5**	**-2**	**2**	**0**	**97**	**60**
	CC l)	9	-2	0	-7	0	0	0	100	49
	FC m)	9*	-4*	1*	-7*	-1	1	0	99	49
	IG n)	2*	0	0	-1*	-5	5	0	95	65
	EG o)	1	0	0	-1	-4	4	0	91	74

a) Fodder crops: including clover and silage maize; b) Others: Other cash crops including oilseeds, legumes, root crops, and special crops. c) Int. GL: Intensive grassland; d) Ext. GL: Extensive grassland; e) Aband. GL: Abandoned grassland; f) TGM: average total gross margin; g) SUB: average volume of subsidies; h) Development of land use is represented by the means of the percentage difference between the corresponding scenario and the CAP baseline scenario in % of utilized agricultural area (UAA). Development of TGM and SUB is represented by percentage changes with TGM and SUB in CAP defined as 100%. For the model region (MR), the values represent the values for the complete model region and do not represent the means. i) CAP: baseline scenario according to the final status of the Common Agricultural Policy reform 2003 and climate change of story line B2 and technological progress of Local Stewardship scenario (LS); j) MOD: modulation scenario and climate change of story line B2 and technological progress of Local Stewardship scenario (LS); k) MR: model region; l) Cash crop districts; m) FC: Fodder crop districts; n) IG: Intensive grassland; o) EG: Extensive grassland; * Calculation of mean values and rounding errors result in a sum unequal to zero in this farm type.

Source: authors' calculations

climate change and technical progress nearly compensate for the losses of income.

5. Conclusion and discussion

Because agriculture depends strongly on climate, weather risk due to climate change is seen as a major challenge in agricultural policy (EC, 2006). This has some influence on the "Health Check" aims recently published by the European Union. In this revision process of the present agricultural policy instruments such a more effective Single Payment Scheme and the future of market support are explored. Also the need for adjustments to respond to novel challenges, ranging from climate change to growth in biofuels and water management, but also to current challenges like the preservation of biodiversity, is discussed (COM, 2007).

This modelling study of the Upper Danube catchment in the south of Germany up to 2020 shows that agriculture will benefit slightly from climate change due to the expected increase in crop yields. Taking technological progress into account augments this effect. Therefore, the decrease in agricultural income due to reductions in direct payments can – depending on the scenario chosen – at least partly be compensated for by the increase in yields.

Major conclusions from the results of this study are thus: in the years leading up to 2020 especially agricultural policy developments and – depending on the magnitude of technological progress assumed – will be more important than climate change in determining agricultural land use. However, the impact of climate change will get stronger through the end of this century and may switch from bringing net benefit in the short to medium term to causing net losses for the agricultural sector in the long run. This underscores the necessity of considering measures to alleviate climatic risks, such as irrigation or weather derivatives when discussing future agricultural policies.

Although there is great uncertainty in climate projections, the results from the ACRE calculations largely coincide with recent findings from several other studies regarding Central European regions. These studies concur that agricultural land use changes induced by climate change are likely to be relatively small within the next decades (AUDSLEY et al., 2006; ZEBISCH et al., 2006; van MEIJL et al., 2006; KLIJN et al., 2005; GÖMANN et al., 2005).

Projections of the regionalised agricultural sector model RAUMIS within the interdisciplinary model network GLOWA-Elbe expects minor land use changes for individual production processes for the Elbe river basin (Eastern Germany) in the year 2020[4] due to climate induced yield changes. These changes are expected to be limited to a range of ± 1% of UAA and hence will not be perceptible in the landscape picture (GÖMANN et al., 2004: 207). Agricultural income (Net Value Added) in this study is expected to decline slightly by about -6% compared to the reference situation in the year 2020 due to simulated yield depressions, if price effects are not considered (GÖMANN et al., 2006: 54). However, if considering adjustments of net photosynthesis and transpiration due to higher atmospheric CO_2 concentrations, crop yield simulations of the underlying eco-hydrological modelling system SWIM shows predominantly crop yield increases for the Elbe river basin (KRYSANOVA et al., 2004: 438), and thus, supports the evidence of increasing agricultural income due climate change.

Simulations by the EURURALIS study indicate correspondingly to the results of the current study that climate change in the short run influences crop yields on European scale and hence agricultural land use only marginally is changed and predominantly by CO_2 fertilisation effects (van MEIJL et al., 2006: 32). Liberalisation and agricultural policy changes in combination with positive feedback loops in crop yields in the A1 + World Market scenario are expected to cause large areas of agricultural land in EU 15 to become abandoned (VERBURG et al., 2006: 48) or partly be found extensively (van MEIJL et al., 2006: 31) with important consequences for the character and quality of these landscapes (VERBURG et al., 2006: 53). These changes are expected to be less drastic for the B2+ Local Stewardship scenario[5] (VERBURG et al., 2006: 53).

However, one has to take into account that regional economic models are limited in their ability to represent changing climate conditions. Both long-term simulations and the consideration of possible weather variation and extremes during the year are beyond the scope of ACRE. Valid and serious projections can be made only for medium-term projections, which are too short to incorporate the more severe climatic changes expected at the end of this century.

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[4] Under the assumption that changes of the climate scenario for the year 2046-2055 in comparison to 1951-2000 (GERSTENGARBE et al., 2003) are becoming effective already by the year 2020 (GÖMANN et al., 2006: 48).

[5] "Word Market scenario" and "Local Stewardship scenario" correspond in terminology of EURALIS to "Global Economy scenario" and "Regional Communities scenario", respectively.

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