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Modelling the impact of global change on regional agricultural land use in alpine regions

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Climatic and socio-economic changes influence agricultural production. In order to estimate possible future impacts on agricultural production in the alpine regions of the Upper Danube catchment, scenarios of climate and socio-economic change were simulated using the regional optimisation model ACRE-Danube.

1. Context and motivation

1.1 Global change and agricultural production

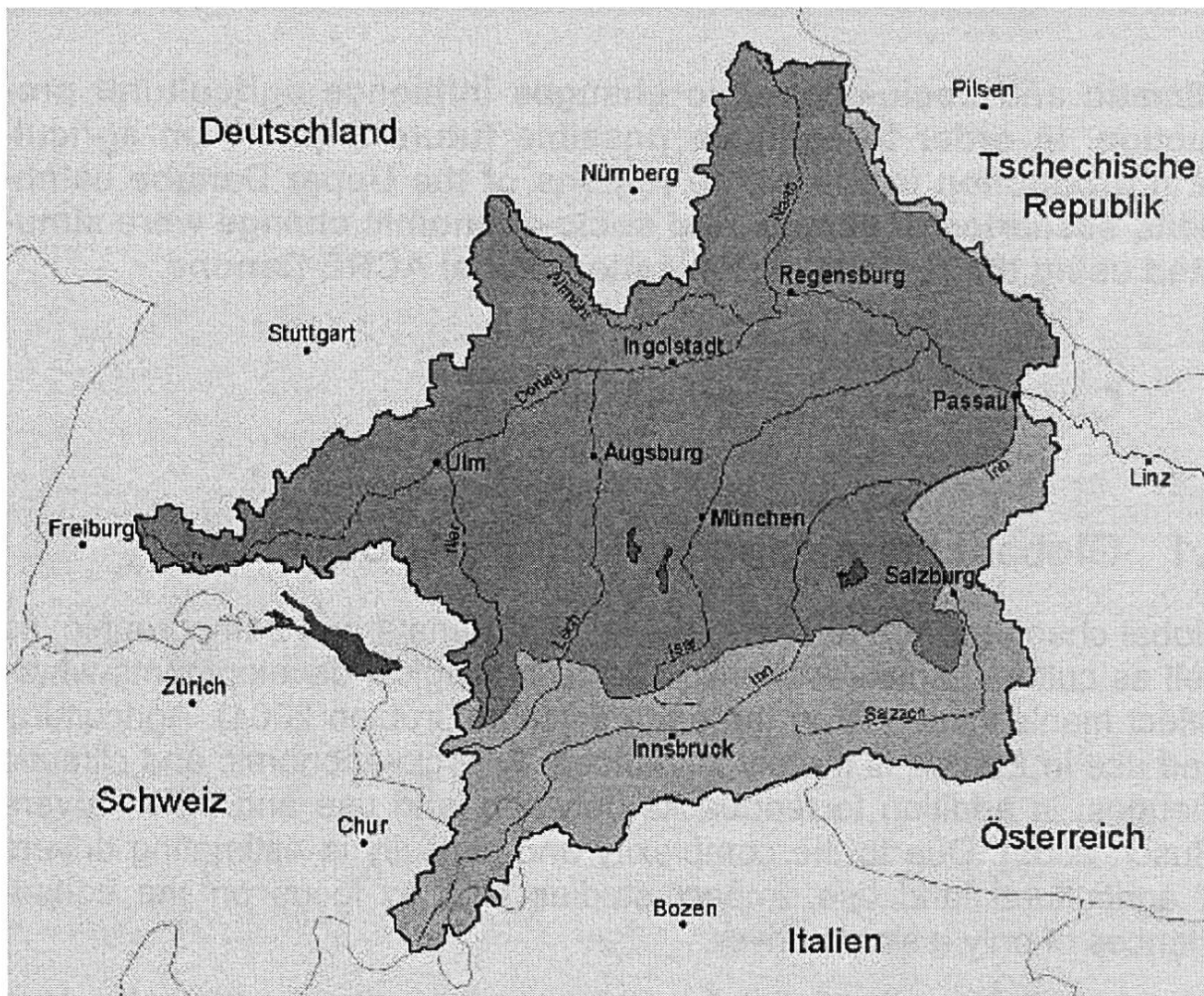
Global change refers to changes in global climate and demographic, as well as cultural, socio-economic and technological developments which reflect man's influence on the earth system (Crutzen 2004). Agricultural land use in Europe is largely influenced by socio-economic and climatic changes, in addition to feedbacks between land use and other drivers (Busch 2006). Due to the complexity and difficulty in estimating drivers of agricultural land use, impact studies tend to focus on the consequences of only a single driver.

The expected impact of climate change on agriculture in alpine regions is the subject of several qualitative studies, and has been reported for Switzerland in 2050 by Fuhrer et al. (2007). Potential effects for Austria have been investigated by Mayer et al. 2005, Soya et al. 2005, and Formayer et al. 2001.

Few interdisciplinary studies exist on a regional scale which explicitly consider impacts of global change. A detailed review of quantitative land use/cover change studies for Western Europe was conducted by Busch (2006), whereby two were evaluated as suitable for regional agricultural analysis. In an additional review by the author, further studies with a regional focus were identified; details are given by Wirsig (2007).

1.2 Investigation area: the Upper Danube basin of Austria

The Upper Danube basin covers an area of 77,000 km², primarily in Germany and Austria. Approximately 55 % of the catchment area is cultivated; hence agriculture represents the major land use.



Source: Diercke (1992)

Figure 1: The Upper Danube Catchment.

The Upper Danube investigation area includes a total of 74 districts, 16 of which are located in Austria. The region including the three States of the Czech Republic, Switzerland and Italy contribute only to a minor degree and are therefore not considered.

The Alps and their forelands enforce large gradients in climate, vegetation and water supply within a comparably small area (Mauser and Ludwig 2002). The Upper Danube basin of Austria therefore represents

an ideal research area for investigating impacts of global change on regional agricultural land use in alpine regions. Due to local conditions (e.g. high annual precipitation, topography), grassland farming is the major agricultural land use in the Alps and the southern alpine foreland. Dairy farming is the predominant practice in these regions, whereby average farm sizes tend to be larger than in the rest of the Danube catchment (Wirsig et al. 2006). In the northern alpine foreland, cereals and fodder crops are cultivated to a minor extent (Table 1).

Table 1: Agricultural land use in the Upper Danube basin of Austria

| Region | UAA | Arable land | Grassland |
|-------------|--------|-------------|-----------|
| | ha | % | % |
| Reutte | 25460 | 0 | 100 |
| Zell am See | 107544 | 0 | 100 |
| St. Johann | 72798 | 0 | 100 |
| Kitzbühel | 48903 | 0 | 100 |
| Hallein | 24575 | 0 | 100 |
| Landeck | 67989 | 1 | 99 |
| Bludenz | 52979 | 1 | 99 |
| Bregenz | 43686 | 1 | 99 |
| Imst | 50200 | 3 | 97 |
| Schwaz | 56838 | 3 | 97 |
| Kufstein | 40316 | 4 | 96 |
| Innsbruck* | 65088 | 8 | 92 |
| Salzburg* | 45713 | 8 | 92 |
| Braunau | 57737 | 48 | 52 |
| Schärding | 38440 | 53 | 47 |
| Ried (Inn) | 40291 | 60 | 40 |

* Statistical data for urban and hinterland was aggregated. UAA: Utilised Agricultural Area.

Source: Statistik Austria 1996

2. Modelling land use/land cover change

2.1 Economic models of land use/land cover change

Mathematical programming models are widely used for modelling changes in land use or land cover, since they are able to address the core decision making process that drive agricultural land use/land cover change (Lambin et al. 2000) and offer a unique opportunity to link economic elements with ecological and biophysical elements (Buysse et al. 2007). Scaling is a major issue in land use/cover change modelling (Verburg et. al. 2006); since land use is the result of multiple processes that act on different scales, no single model can address both the driving factors that operate on global level and the local variations within it (Verburg 2006). Bottom-up approaches are important to adequately reflect the proximate actors of agricultural land use (Busch 2006). Since detailed farm surveys on a regional scale would be extraordinary costly, data acquisition is generally limited to secondary statistical information, which is only available on a certain administrative level, depending on the type of data, whether at the state, county or municipality level (Umstätter 1999). Positive Mathematical Programming (PMP) models can help to overcome the lack of data available from statistical sources, such as production costs (Umstätter 1999). Feedbacks related to the use of models as policy support tools for stakeholders, in particular decision makers, are an important issue in land use/cover change modelling (Verburg et. al. 2006). PMP models are able to take real observed behaviour into account and to predict producer's reactions to external changes; this makes them particularly interesting for agricultural policy analysis (Bysse et al. 2007).

2.2 The regional agricultural sector model ACRE

ACRE-Danube is an Agro-eConomic pRoduction model at rEgional-level for the Upper Danube catchment area. The model was developed for the German part of the basin by Winter (2005) within the project GLOWA-Danube.

ACRE is a comparative static partial-equilibrium model which maximises total gross margin at the regional level to find the optimal combination of production activities for each district (regional farm approach). The shortest simulation period is one year. ACRE uses a bottom-up ap-

proach to simulate regional agricultural land use with a high level of detail, both in terms of spatial scale and number of production activities. It explicitly spatially allocates 24 food and non food crops at NUTS 3 level, taking different production intensities into account, as well as 15 production processes for livestock, and includes ecological and socio-economic indicators of landscape functions. The main purpose of ACRE is the regional analysis of the impact of global change and policy measures (quotas, subsidies, 2nd pillar of CAP etc.) on agricultural land use. ACRE has been successfully applied in two interdisciplinary projects, details are described by Henseler et al. (2006).

2.2.1 The calibration method

The calibration method is the Positive Mathematical Programming (PMP) published by Howitt (1995). ACRE is based on the extension of PMP published by Röhm & Dabbert (2003). Whereas the standard approach estimates production functions for the same crop under different cultivation conditions separately from one another, the extended method introduces variant activities alongside the main activities to ensure a closer dependency between variant activities than between the main activities. This enhances the extended PMP approach to allow simulation of different production variants, (e.g. intensive winter wheat production and extensive winter wheat production) alongside the main crop production activities

2.2.2 The process analytic approach

The model comprises a process analytical approach. Cash crops or fodder crops for livestock production can be produced, and the animals produce manure which is used for fertilisation in crop production. Both prices for crops and animal products, as well as premiums, influence the total gross margin. Mineral fertiliser, feed concentrates and water are purchased. In the optimisation process, ACRE maximises the total gross margin for each district by optimising the acreage of crops and the number of animals with respect to the scenario constraints. Trade activities between the districts are not defined. To simulate policy instruments, CAP premiums (1st pillar of CAP), environmental programmes and payments for less favoured areas (2nd pillar) are implemented for the period from 1995 to 2013.

2.2.3 Model data

ACRE has been calibrated with regional statistical production data for the year 1995. The production processes in ACRE are formulated according to publications of the German Association for Technology and Structures in Agriculture (KTBL). Data on production intensity were gathered through expert interviews (Winter 2005).

3. Global change scenarios

Scenario planning allows the identification of a range of possible futures and estimation of the consequences of possible interventions. Each scenario is based on a logically consistent, internally coherent and plausible set of assumptions (see Meadows et al. 2004; IPCC 1994). Theoretically, the scenario space contains an infinite number of scenarios; typically, only a few of them are considered. The scenarios used in this study combine published socio-economic and climate change scenarios.

3.1 Climate change scenarios

Projections of climate induced yield changes for winter wheat have been reported for Lower Austria by Alexandrov et al. (2002). Although projections indicate that crop and grassland yields in alpine regions may increase due to higher levels of CO₂ and a prolonged vegetation period (Fuhrer et al. 2007), drought risks may also increase; e.g. during the drought year 2003 average yield reduction for Austria ranged from 12 % (wheat) to 15 % (grassland) (Soja et al. 2005). Annual variability of temperature and precipitation in summer are likely to increase substantially in Europe, (Giorgi et al. 2004). Both increased climate variability and extreme weather events could increase the risk of yield reduction, particularly for cereals (Soja & Soja 2003).

In order to simulate climate change, crop specific and spatially explicit yield data from the crop growth model ROIMPEL were used (Simota 2007). The results for 10 different crops and four NUTS 2 regions were disaggregated, for each crop and model district, respectively. The scenarios consider different effects of climate change and increasing CO₂, as well as technological advances (in particular those in crop management and breeding). For each IPCC Special Report on Emissions Scenario (Nakićenović 2000), the disaggregated yield changes due to cli-

mate change from the ROIMPEL model (Simota 2007) were used, in combination with the technological progress rates described in the ACCELERATES study (Anonymous 2004; Table 2).

Table 2: Average yield changes for the all Austrian districts of the Upper Danube river basin and for total crop and grassland area, under different SRES scenarios for 2020 (percentage relative to base yield)

| | 2020 | | | |
|-----------------------------|------------|------------|------------|------------|
| | A1 | A2 | B1 | B2 |
| Climate and CO ₂ | 111 | 111 | 111 | 112 |
| Technological advance | 167 | 131 | 130 | 104 |
| Total | 178 | 142 | 141 | 116 |

A1 (Global economic world), A2 (Regional economic world), B1 (Global environmental world), B2 (Regional environmental world).

Source: own calculations based on Simota (2007) and Anonymous (2004)

3.2 Socio-economic scenarios

Agricultural policy conditions are considered up to the year 2013 and assumed to remain valid for the scenario year 2020. The CAP reform 2003 is modelled in ACRE-Danube by assuming reformed payments according to BMLFUW (2003) and AMA (2005). Single Farm Payments (SFP) were derived for the Austrian districts on the basis of the calculated average of direct payments received for crops and livestock, as well as the reference quantity of milk for the period from 2000 to 2002. Partial decoupling of premiums (100 % suckler cow premium remains coupled, slaughter premium is not considered) and additional aids are included, as well as changes in set-aside rates (Table 3).

Table 3: Direct payments and set-aside rates in Austria

| Crops | Agenda 2000 | CAP reform |
|-----------------------|--------------------|-------------------|
| | Euro/ha | Euro/ha |
| Suckler cow | 230 | 230 |
| Special premium bulls | 210 | - |
| Ewes | 21 | - |
| Cereals & Maize | 332 | SFP |
| Oilseeds | 332 | (45)+ SFP |
| Protein crops | 382 | (55,75)+ SFP |
| Set-aside | 332 | SFP |

SFP: Single Farm Payments (81-27 Euro/ha)

Source: BMLFUW 2001, 2003

Selected elements of cross compliance (e.g. grassland maintenance) are taken into account, while modulation is not considered. Agri-environmental payments are implied for grassland (Table 4).

Table 4: Agri-environmental payments for grassland in Austria

| Grassland | Agenda 2000 | CAP reform |
|---------------------|--------------------|-------------------|
| | Euro/ha | Euro/ha |
| Pasture for cutting | 73 | 110 |
| Alpine pasture | 44 | 66 |
| Rough pasture | 44 | 66 |
| Other | 73 | 110 |

Source: BMLFUW 2001, 2003

Changes in subsidies and prices were derived from the socio-economic scenarios described in the ACCELERATES study (Anonymous 2004) and are identified by the symbols WM (World Markets), RE (Regional Enterprises), GS (Global Sustainability) and LS (Local Stewardship). Key assumptions include a reduction of interventions in agricultural commodity markets after revision of the Common Agricultural Policy

(CAP), particularly in the global scenarios (WM and GS). With regard to the second pillar of the CAP, a strong reduction in the WM scenario and a strong increase in the LS scenario are assumed (Anonymous 2004). Changes in subsidies were related to subsidies in the CAP reform 2003 scenario, as projected for the end phase in 2013 and assumed to remain constant up until 2020 as SFP. Price changes were related to the prices according to which ACRE-Danube was calibrated. Table 5 shows variables for the parameters which were selected as scenario inputs, based on ACCELERATES (Anonymous 2004).

Table 5: Implementation of changes in prices and subsidies for 2020.

| | 2020 | | | |
|-------------------------------|------|-----|-----|-----|
| | WM | RE | GS | LS |
| CAP | | | | |
| Single Farm Payments | 0 | 0 | 91 | 107 |
| Agri-environmental payments | 81 | 105 | 92 | 121 |
| Prices | | | | |
| Cereals | 83 | 92 | 102 | 112 |
| Grain maize | 91 | 99 | 105 | 106 |
| Legumes | 81 | 93 | 93 | 108 |
| Oilseeds | 82 | 90 | 94 | 106 |
| Root crops | 88 | 98 | 113 | 124 |
| Special crops | 82 | 94 | 90 | 106 |
| Milk | 88 | 96 | 104 | 119 |
| Dairy cattle | 88 | 96 | 104 | 119 |
| Meat from poultry, beef, pork | 96 | 98 | 101 | 110 |
| Cattle for fattening | 96 | 98 | 101 | 110 |
| Pigs | 96 | 98 | 101 | 110 |
| Eggs | 88 | 96 | 104 | 119 |
| Ride Horses | 96 | 98 | 101 | 110 |

WM (World Markets), RE (Regional Enterprises), GS (Global Sustainability) and LS (Local Stewardship).

Source: based on Anonymous (2004)

4. Results

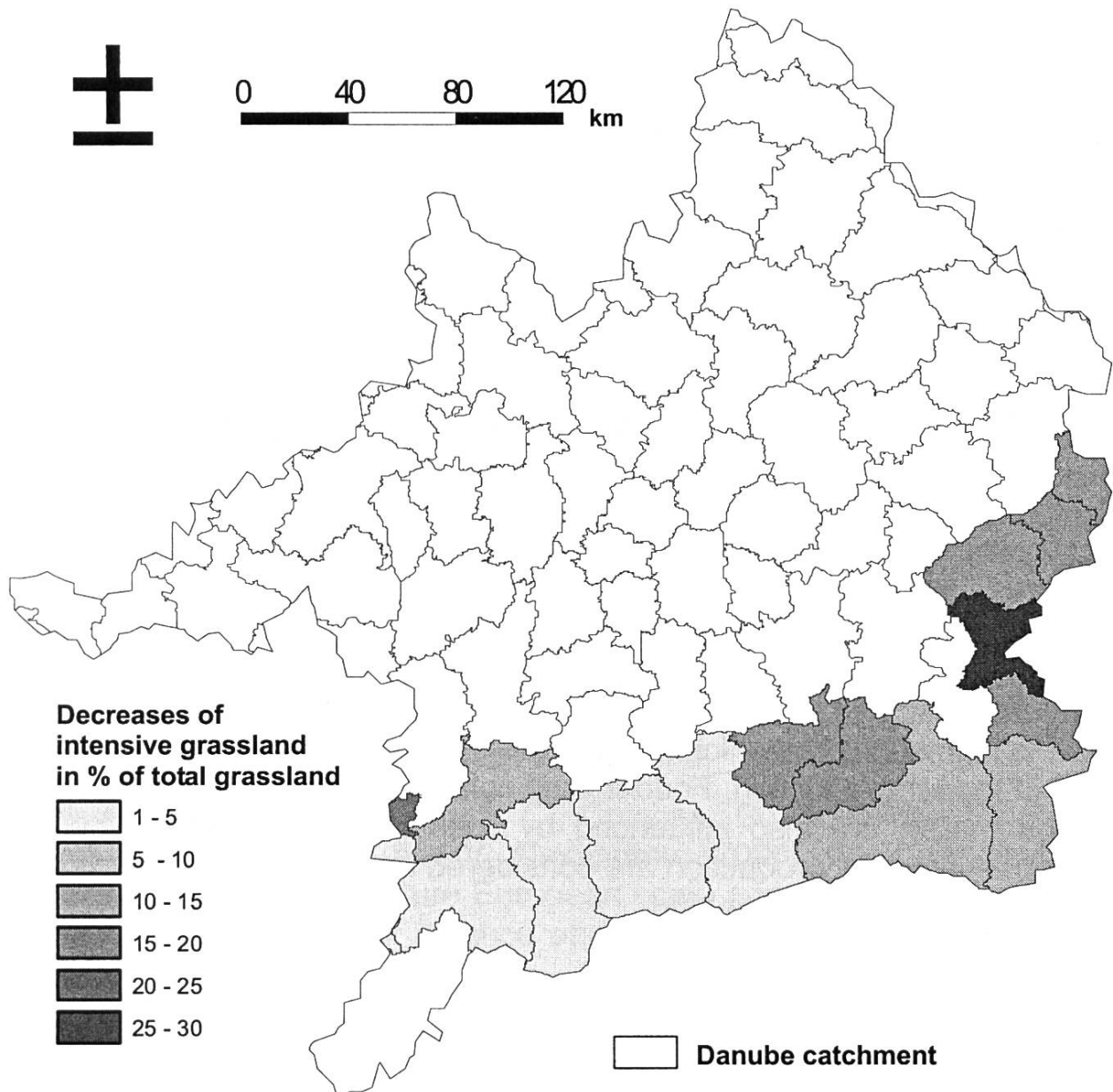
The comparison between the reference scenario (Agenda 2000 with no changes of crop productivity) and the global change scenarios in the year 2020 (CAP reform scenario, and assumed socio-economic and crop productivity modifications) illustrates that areas of agricultural land are abandoned in all global change scenarios (Table 6). Grassland production is, in general, either extensified or abandoned, with the least in the LS scenario. Fodder crops (silage maize and clover) tend to decrease, whereas grain maize increases. Cereals (aside from grain maize) increase only in the WM scenario. Set aside area increases in all scenarios save for in the WM scenario, where no obligatory set aside quota is assumed. The total gross margin (not shown) increases in general, particularly in the LS scenario. At the same time, nitrogen input (not shown) increases least for the LS scenario.

Table 6: Shares in agricultural land use for the Austrian part of Danube river basin under different global change scenarios for the year 2020

| | 2000 | 2020 | | | |
|------------------|------|------|----|----|----|
| | | WM | RE | GS | LS |
| Crops | | | | | |
| Cereals | 15 | 18 | 14 | 15 | 14 |
| Clover | 20 | 15 | 15 | 15 | 17 |
| Silage maize | 18 | 12 | 14 | 13 | 14 |
| Grain maize | 5 | 8 | 7 | 7 | 6 |
| Set aside | 3 | 0 | 9 | 9 | 10 |
| Abandoned AL | 0 | 1 | 6 | 4 | 5 |
| Grassland | | | | | |
| Extensive | 61 | 67 | 67 | 67 | 67 |
| Intensive | 30 | 21 | 25 | 26 | 30 |
| Abandoned GL | 9 | 13 | 8 | 7 | 3 |

WM (World Markets), RE (Regional Enterprises), GS (Global Sustainability) and LS (Local Stewardship).

Source: own calculations



Source: own calculations

Fig. 2: Regional changes of intensive grassland farming in the Austrian part of Danube river basin for the World market scenario (WM) in the year 2020.

Grassland farming is extensified for all districts in the Upper Danube basin of Austria, particularly in the alpine foreland. Whereas the alpine regions tend to shift from intensive grassland farming towards expansion of alpine pastures (e.g. Bregenz), grassland farming in the alpine foreland is abandoned over large areas (e.g. Salzburg).

5. Discussion

The generally observed reduction in agricultural area, particularly for grassland (up to 13 % of grassland being abandoned), is due to large assumed increases in yield driven by technological development, in combination with variations in feeding of dairy cattle and subsidies for grassland, which were likewise detected in the ACCELERATES study (Audsley et al. 2006). In comparison to the reference scenario, the shift towards extensive grassland farming (Agenda 2000) remains stable for all scenarios and is a result of the CAP reform, as reported by other studies (Schmid 2004, Schmid & Sinabell 2004). The increase in set-aside area, except in the World Market scenario where no obligation is assumed, is caused by the increase of prescribed set-aside area in the CAP reform. The World Market scenario shows a strong regional differentiation, indicating that liberalisation will further enhance a dual development of agricultural land use. With respect to the preservation of agricultural landscapes (and other indicators not shown, such as farm income and nitrogen input), the LS scenario can be considered beneficial, due to high subsidies which make grassland farming attractive, irrespective of fodder production. Fodder crop cultivation, particularly clover and silage maize, are also influenced by scenario assumptions, whereas changes in cereal production are considered less important in relation to their total share of arable land.

6. Conclusion

The availability of sufficiently detailed regional information on future consequences of global change is essential to regional decision makers. ACRE takes real observed behaviour into account and adequately reflects the proximate actors of regional agricultural land use, with a high level of detail. Further, it allows for integration of indicators which address the demands of different groups of society.

According to the scenario calculations presented here, global change in the Austrian Upper Danube catchment will bring about slight changes in agricultural land use; in particular, grassland production will be either extensified or abandoned. The influence of climate change appears to be small. However, it should be noted that several important factors and their potential interactions are currently not or only partially considered, e.g. the impact of pests and diseases.

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