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# INTEGRATED LAND USE MODELLING OF CLIMATE CHANGE IMPACTS IN TWO AUSTRIAN CASE STUDY LANDSCAPES AT FIELD LEVEL

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**Paper prepared for presentation at the EAAE 2014 Congress  
'Agri-Food and Rural Innovations for Healthier Societies'**

August 26 to 29, 2014  
Ljubljana, Slovenia

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## **Abstract**

This article presents an integrated modelling framework (IMF) at field scales including a bio-economic farm optimization model. It is applied on two contrasting Austrian landscapes to analyze climate change and CAP policy reform impacts in 2040. Changing policies reduce farm gross margins by -36% and -5% in the two landscapes respectively. Climate change increases gross margins and farms can reach pre-reform levels on average. Climate induced intensification such as removing of landscape elements and increasing fertilization can be moderated by an agri-environmental program (AEP). However, productivity gains from climate change increase the opportunity costs of AEP participation.

## **Keywords**

integrated land use modelling, agri-environmental program, climate change, landscape

## **1 Introduction**

Knowledge on farm level adaptation is crucial to understand climate change impacts and economic responses even at larger scales of spatial aggregation (Reidsma et al., 2010). Hence, different methodologies have been employed to analyze climate change impacts and farm adaptation. They can be categorized in (i) qualitative and quantitative surveys, (ii) econometric analyses of observed land use and farm management data, and (iii) integrated land use modelling (ILM). For instance, Olesen et al. (2011) surveyed 50 experts on 13 environmental zones in Europe to study observed and expected climate change impacts as well as farm adaptation for major field crops, grapevine, and grasslands. In contrast, Reidsma et al. (2009) used econometric methods to analyze data from the European farm accountancy network by estimating climate change impacts and adaptation behavior for different farm types and regions. Both surveys and econometric methods can provide important insights in farm level adaptation but also face limitations. Surveys among farmers and agricultural experts can generate empirical evidence in developing theories and hypothesis but can be expensive. Experts may have limited knowledge on actual farm behavior and are prone to substitute observations with their normative expectations (Mignolet et al., 2004). Such biases can be reduced by surveying farmers directly. Periodical repetition can reveal differences between stated and actual behavior. However, individual farmers may also lack knowledge about regional circumstances apart from their detailed farm level experiences. Both experts and farmers are exposed to overestimate recently observed events for the future while neglecting others (Mitter et al., 2014). They may be conservative in envisioning fundamental system changes over time periods of several decades and may struggle with the high complexity and uncertainty of agricultural systems. Econometric analysis can overcome some of these limitations, if data of long time series (i.e. 30 years) and structural stratification is available. Predictive positive quantitative models may be applied despite their limited suitability for ex-ante assessments under expected circumstances outside the observed range. This can be challenging in climate change impact studies, where future changes likely are more fundamental than those observed in the past. In contrast, ILM on climate change impacts and adaptation usually consist of economic land use optimization models and bio-physical process models on plant and livestock production. Consequently, ILM usually rely on interdisciplinary knowledge about systems behavior, which is often modelled by integrating disciplinary concepts, data, and scenarios. Such demanding prerequisites enable ILM to overcome two major constraints of surveys and econometric methods, i.e. ex-ante analyses of systems with high complexity and uncertainty.

ILM climate change impact and adaptation studies are available at different spatial scales from field (e.g. Lehmann et al., 2013) to regional (e.g. Henseler et al., 2009; Leclère et al., 2013) and global levels (e.g. Nelson et al., 2013). Global as well as large-scale regional studies usually model price effects from climate change endogenously. The representation of market effects is usually accompanied by coarse spatial resolution of bio-physical impact characteristics and superficial representation of farm management and endowments. Consequently, large scale studies hardly take farm level adaptation into account so far. On the opposite, field level studies can consider high resolution bio-physical impact data to evaluate the effectiveness of farm adaptation measures. As in the case of large scale models, lacking interactions at the farm level, such as competition for land, labor and capital resources aggravate conclusions on the economic efficiency of adaptation from a farm perspective (Gibbons and Ramsden, 2008).

Consequently, the farm level appears superior for the representation of land use choices in ILM studies on climate change adaptation and complement global, regional, and field level studies. ILM at the farm level is synonymous to bio-economic farm modelling (cf. Janssen and van Ittersum, 2007). A number of different studies on climate change impacts and farm adaptation are available already at this scale. They are applied to analyze responses of different farming systems (e.g. Kanellopoulos et al., 2014; Dono et al., 2013), which shall support farm and policy decision making. Other applications focus on inter-annual farm processes and decision making such as scheduling of field work (e.g. Aurbacher et al., 2013). Another group of studies applies bio-economic farm modelling to analyze climate change effects on land use and the environment at the landscape to small regional level (e.g. Briner et al., 2012). Consequently, these studies aggregate farm level model output, either from all individual or selected farms in a small region. A high spatial resolution provides interfaces for landscape level analysis such as on landscape appearance and biodiversity conservation.

Climate change impact analysis for Austria indicate moderate increases of average producer rents up to 2040 due to more favorable production conditions and autonomous adaptation in agriculture (Schönhart et al., 2013). However, the impacts are expected to be i) heterogeneous with winners and losers among regions and farm types, ii) uncertain due to unpredictable changes in precipitation patterns and extreme events, and iii) unclear with respect to environmental consequences such as on biodiversity and landscape appearance. Agricultural land use change is among the major drivers for visual landscape appearance, environmental quality, and biodiversity, which are affected, experienced, and measured mainly at field to landscape levels.

In this article, we present an integrated modelling framework (IMF) at the farm level, which has already been applied in studies on the effectiveness of agri-environmental programs in an Austrian case study landscape (e.g. Schönhart et al., 2011a). The IMF is applied on two contrasting grassland and cropland dominated landscapes in Austria and extended to analyze climate change impacts on farm production and adaptation as well as on the abiotic and biotic environment. The IMF shall address issues i-iii raised above and shall support analyses of landscape appearance, biodiversity conservation, and abiotic environmental impacts from agricultural adaptation measures at field, farm and landscape level. Section 2 explains the method, data as well as applied climate and socio-economic scenarios. In this article, we consider the climate impacts on the maintenance of orchard meadows and the participation in agri-environmental programs. Section 3 presents results, which are discussed in section 4. Section 4 also provides an outlook on open research questions and policy conclusions.

## 2 Data and Methods

### 2.1 Integrated Modeling Framework (IMF)

The IMF combines the crop rotation model CropRota (Schönhart et al., 2011a; Schönhart et al., 2011c), the bio-physical process model EPIC (Williams, 1995) and the bio-economic farm model FAMOS[space] (Schönhart et al., 2011b; see Fig.1). The choice on crop rotations is fundamental to the economic and environmental outcomes of agricultural systems. Nevertheless, knowledge on actually applied crop rotations is usually limited. In the IMF, the crop rotation optimization model CropRota is applied to fill this empirical knowledge gap. CropRota provides typical crop rotations at farm and regional level based on observed land use and agronomic rules. Crop rotations are input to EPIC together with geo-referenced field and climate data and a portfolio of crop management measures to simulate crop yields and environmental outcomes including nutrient and soil sediment losses as well as soil organic carbon stocks. EPIC has already been applied several times at 1km<sup>2</sup> resolution to support climate change impact and adaptation studies for Austria (e.g. Schönhart et al., 2013; Mitter et al., 2014). In this study, simulation units are the individual fields in the case study landscapes. CropRota and EPIC are sequentially linked to FAMOS[space], i.e. crop rotations, crop yields and environmental outcomes are explicitly represented in FAMOS[space]. FAMOS[space] is a mixed-integer mathematical programming model at farm level. It maximizes total gross margin subject to farm specific resource endowments such as family labor, livestock housing capacity, and fields by finding optimal management choices including adaptation measures. The latter includes crop rotation choices, establishment or removal of landscape elements (i.e. orchard trees) and land use intensity levels (i.e. fertilizer application rates, mowing frequency on meadows). Further adaptation measures available in FAMOS[space] such as irrigation or soil management (e.g. cover crops and minimum tillage) have not been considered in this study, yet. An algebraic representation of FAMOS[space] is provided by Schönhart et al. (2011b).

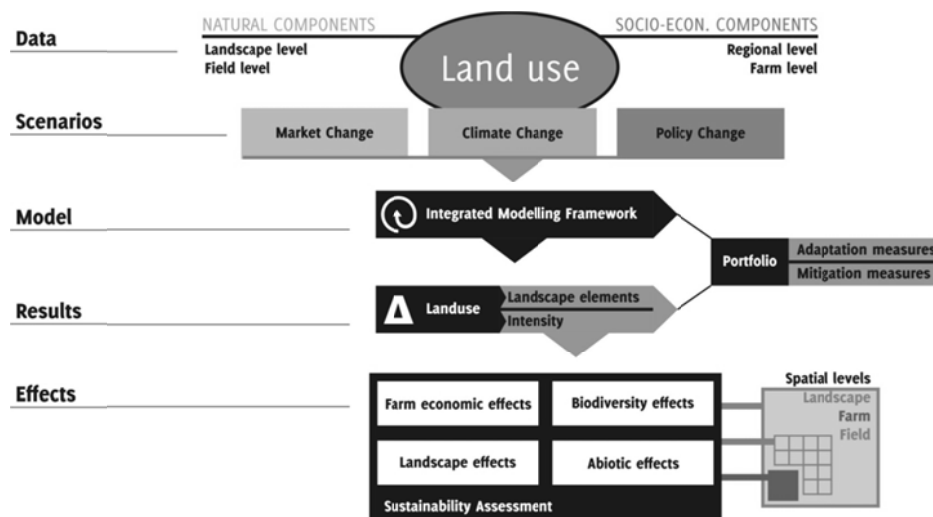


Figure 1. The integrated modelling framework (IMF; own illustration).

### 2.2 Data

Main data sets in the IMF include data on farm resource endowments, markets, bio-physical site characteristics, land use and management as well as landscape structure. IACS (Integrated Administration and Control System) data from several years (2000-2008) serve as central data source, in which fields and farms are described in detail with respect to crop and

livestock production, agri-environmental management measures, and subsidies from the 1<sup>st</sup> and 2<sup>nd</sup> pillar of the Common Agricultural Policy (CAP). Gross margins on annual farm production activities are calculated from the standard gross margin catalogue (BMLFUW, 2008) and literature surveys. Annuities for production activities with investment character are calculated for permanent crops. Farm labour requirements are based on a detailed set of standard working units (Handler et al., 2006) and literature reviews. A digital soil map (Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft, BFW), and a digital elevation map (Bundesamt für Eich- und Vermessungswesen, BEV) describe the field characteristics of the case study landscapes. Automatic pixel segmentation and semi-automatic classification have been applied to identify discrete landscape elements (for a description of this method, see Schauppenlehner et al., 2010).

### 2.3 Case Study Landscapes

The research project follows a case study approach in two spatially proximate landscapes of the Austrian Mostviertel region (rectangles with ~1,500 ha each). The region has been chosen due to its variety in land uses, the importance of landscape elements such as orchard meadows, and its pronounced land use intensity and climate gradients. It is characterized by an intensively managed rather homogeneous cropland dominated landscape in the North and a more extensively managed grassland dominated heterogeneous cultural landscape in the South. Parts of the South are also located in the montane zone where afforestation may threaten traditional agricultural land uses and landscapes. Consequently, the case study region features a large diversity of farms in terms of farm type (mixed farms, arable farms and livestock farms), farm size, and production intensity. In order to cover the total area in each case study landscape, farms have been selected if they cultivate at least one field in one of the two landscapes. Therefore, 231 farms are included in total.

### 2.4 Climate and Socio-Economic Assumptions

Simulations in the IMF are based on scenarios to anticipate changes in climate, market prices, and policy instruments. These climate scenarios influence the bio-physical output of EPIC, while the socio-economic scenarios only impact the choices of production and management measures in FAMOS[space]. To analyze climate change impacts, we apply three contrasting climate change scenarios and four underlying socio-economic scenarios. The climate change scenarios with daily resolution are based on a statistical climate model and historic trend observations (Strauss et al., 2013). A significant temperature trend has been observed for the past, which is extrapolated to about +1.6°C for Austria in 2040. Scenarios on precipitation have been developed to capture the inherent uncertainties (see Table 1). Scenario CS01 imitates past precipitation patterns, CS05 and CS09 include +20% and -20% in absolute annual precipitation sums, respectively, with daily precipitation patterns identical to past observations.

Table 1. Scenario overview (own construction, AEP = agri-environmental program).

Scenario name	AEP	CAP reform	Climate change in 2040	
			Δ temperature (°C)	Δ precipitation (%)
REF_2008	no	no	0.0	0%
BAU_2008	yes	no	0.0	0%
REF_2040	no	yes	0.0	0%
BAU_2040	yes	yes	0.0	0%
CS01	yes	yes	+ 1.6	0%
CS05	yes	yes	+ 1.6	+20%
CS09	yes	yes	+ 1.6	-20%

We separate among four socio-economic scenarios, which assume identical market conditions for the reference years 2006-2008 but different policy frameworks. In 2008, the CAP is represented by its main features in the model including coupled livestock payments, active dairy quotas, and decoupled direct payments based on historical reference periods. With respect to the 2<sup>nd</sup> pillar of the CAP, main measures of the Austrian agri-environmental program (AEP) and the less favored area payments are represented. For the period 2040, we assume those policy changes, which appear relatively certain today. They include the abolition of dairy quotas, decoupling of suckler cow premiums as well as the shift from a historically referenced direct payment system towards a regional system with premiums of 280€/ha for cropland and intensively managed grassland and 70€/ha for alpine meadows and extensive pastures. The AEP measures represented in FAMOS[space] are assumed to be the same in 2040, i.e. real premium levels and production requirements are maintained. The seven scenarios consist of the following combinations as shown in Table 1. The two reference scenarios REF\_2008 and REF\_2040 do not include the AEP, while this is included in BAU\_2008 and BAU\_2040. Due to the focus on climate effects and agri-environmental policies, market conditions are assumed to remain constant in real terms between the reference period 2006-2008 and 2040. It basically includes production costs, productivity developments from technological change, and changes in output prices. The climate change scenarios CS01, CS05, and CS09 are run with the socio-economic policy assumptions of BAU\_2040.

### 3 Results

#### 3.1 Bio-physical Yield Effects

Figure 2 shows the distribution of yield changes for all 231 farms. It distinguishes among grassland and cropland as well as northern and southern farms. The changes are estimated by aggregating all EPIC yield values for individual crops and management intensities. Consequently, they are not weighted by crop areas and management on a farm and therefore may not represent actual climate change impacts. According to Figure 2, southern farms do benefit more likely from climate change, while results for northern farms appear mixed. This applies for both grassland and cropland where only one scenario CS05 shows some decreases in crop yields but not so for grassland yields.

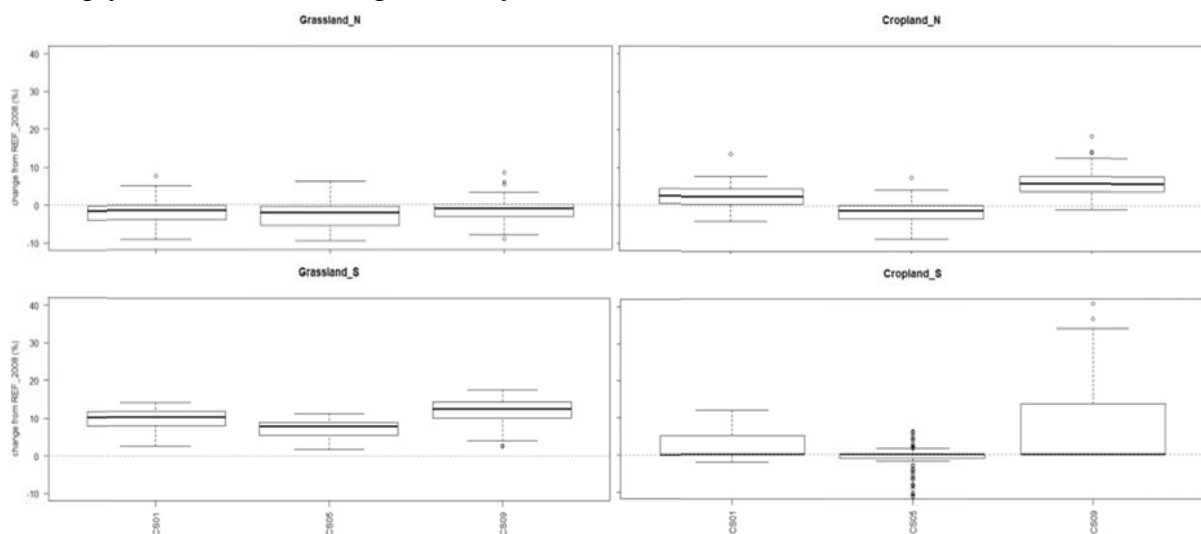


Figure 2. Distribution of yield changes from REF\_2008 on the farms ( $N_{\text{north}}=113$ ,  $N_{\text{south}}=118$ ) for grassland (left) and cropland (right) for the northern (above) and southern (below) case study landscape (own drawing).

On the contrary, yield changes in the northern landscape appear more divers and even change signs among the scenarios with decreasing yields in CS05 again. These results can be explained by the climate gradient along both regions. Obviously, average precipitation does not limit growth currently and higher precipitation in both regions may lead to more soil sediment losses and nutrient leaching.

### 3.2 Economic and Environmental effects

Both, socio-economic and climate changes have considerable impacts on model farms in the case study regions. Figure 3 presents the distributions of changes in total farm gross margins from the reference scenario REF\_2008. In BAU for 2008 and 2040, the introduction of an AEP only slightly increases farm gross margins for some farms although the area managed according to the AEP standards increases about three-fold in both landscapes. Participation in AEP comes along with maintenance of orchard meadows. The CAP changes assumed for the period 2040 in REF\_2040 severely impacts farm gross margins with average reductions of -36% in the northern and -5% in the southern landscape. The introduction of climate change scenarios impacts farm gross margins considerably in the model. Both landscapes show increases compared to a situation without climate change (BAU\_2040). Gross margins in the southern region even increase beyond the REF\_2008 level on average (+18%). There is little effect among the different climate scenarios in both landscapes.

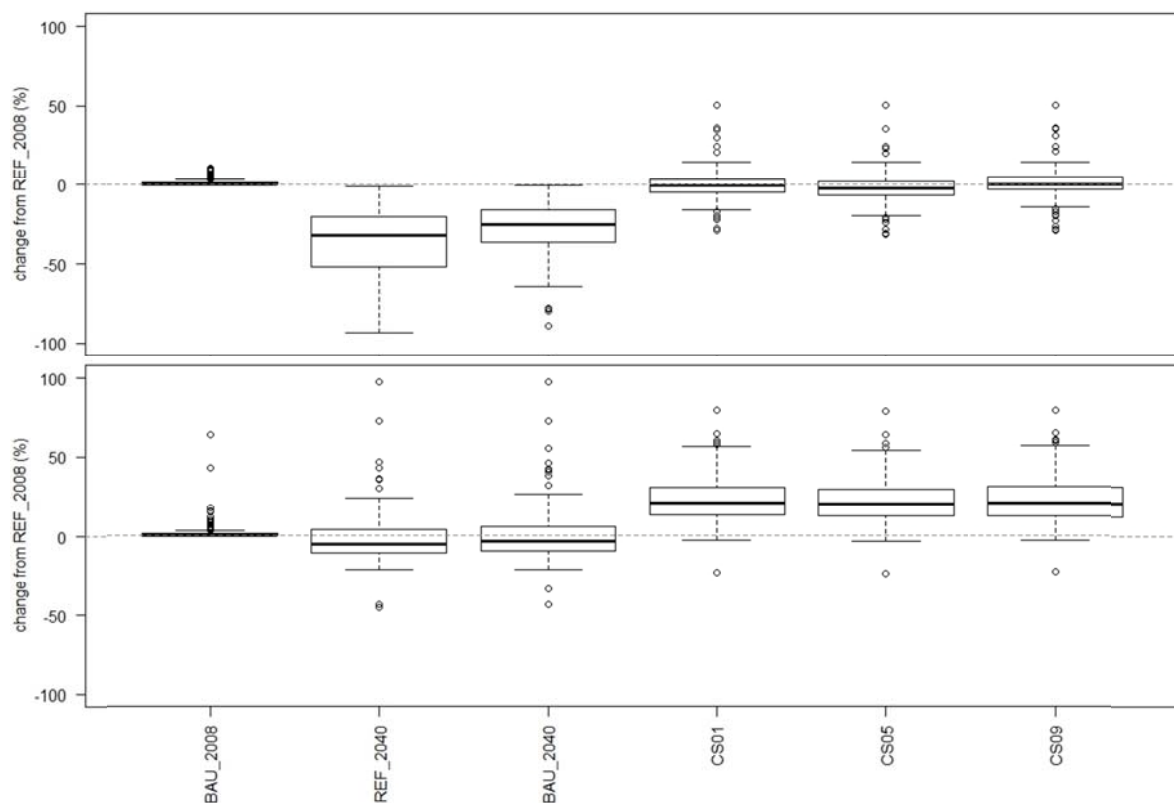


Figure 3. Distributions of changes in total farm gross margin from REF\_2008 for three socio-economic and three climate scenarios (upper graph:  $N_{north}=113$ , lower graph:  $N_{south}=118$ ; scenario description see Table 1; own drawing).

Figure 4 presents land use for REF\_2008 and SC05 in the northern landscape. The maintenance of orchard meadows has been highlighted to show both, the climate change effects as well as the effectiveness of the AEP in impacting landscape structure and appearance.



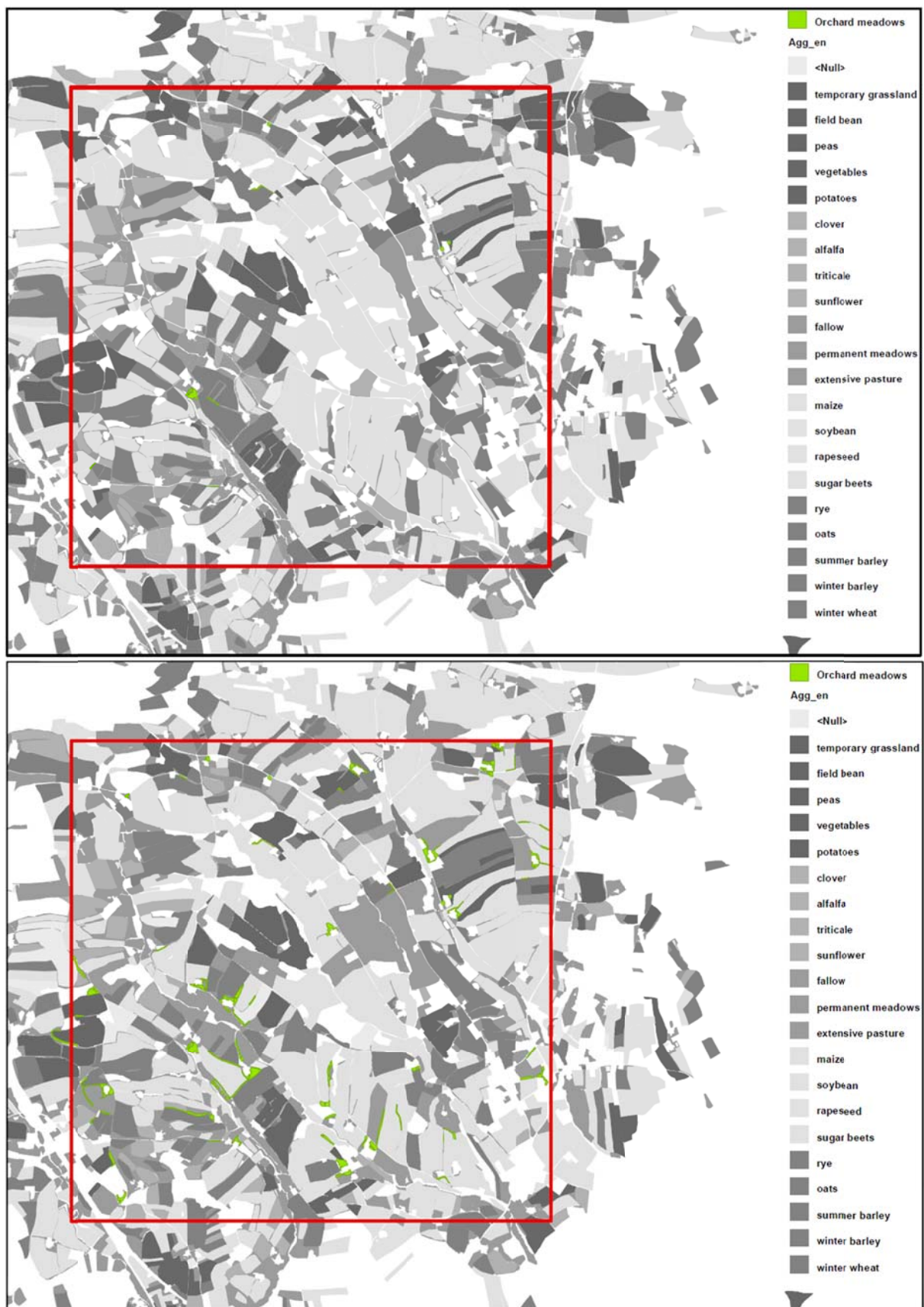


Figure 4. Land use resulting from scenarios REF\_2008 (above) and CS05 (below) in landscape North (own drawing).

Climate change puts pressures on orchard meadows in all three scenarios compared to both BAU\_2040 as well as BAU\_2008. It may be the result of increasing productivity, which also increases the opportunity costs of extensive land use and landscape element maintenance. With respect to land use intensity, the AEP reduces nitrogen application rates by about 10% for both landscapes in BAU\_2008 compared to REF\_2008 and similar patterns are modelled for phosphorus. Even more drastic relative differences are modelled between REF\_2040 and BAU\_2040 (-42% in the North; - 9% in the South from REF\_2040). Fertilizer intensity is increasing in all three climate change scenarios at similar rates. Higher yields demand more nutrients and higher land productivity leads to increasing marginal benefits of inputs such as fertilizers. In the three climate scenarios CS01, CS05 and CS09, fertilizer application remains between REF\_2008 and BAU\_2008 levels indicating a moderate intensification pressure compared to today.

#### **4 Discussion and Outlook**

The results from changes in socio-economic market and policy conditions, such as the introduction of an AEP or implementation of the CAP reform, as well as climate change indicate considerable land use changes in two Austrian landscapes, which may be typical for other Austrian regions as well. The introduction of the AEP only slightly increases farm incomes on average although the area participating in the AEP increases about three-fold in both landscapes. It leads to maintenance of orchard meadows as well as reduction in fertilizer application. On the contrary, the total area within AEP remains well below expected values. It may either be the result of overestimated crop yields in the model or of insufficient representation of variable costs. Both should be further investigated to prove the AEP effectiveness. Increasing productivity from climate change increases the opportunity costs of AEP participation and maintenance of orchard meadows despite the currently unclear impacts of future heat stress on orchard trees in the region. Its effects are similar to those of increasing market prices and likely challenge the design and affordability of AEPs in the future. Such programs should therefore capture changing market and productivity conditions to maintain participation rates. Model results, available studies (e.g. Schönhart et al., 2011c) and observations all indicate insufficient policy mechanisms to maintain orchard meadows in the long run, which calls for more effectiveness in policy design.

With respect to climate change, there is little effect between the three different scenarios. Temperature is more likely limiting production today than precipitation in both case study landscapes. The aggregated bio-physical yield changes (Figure 2) from the climate change scenarios are much more different than the economic effects especially in the northern landscape. This indicates effective farm adaptation via alternative crop choices and intensity levels although further adaptation measures need to be included in the IMF such as the transition from agriculture to forestry, irrigation, or alternative soil mechanization (e.g. cover crops and minimum tillage). Farm level adaptation is subject to the awareness of farmers on climate change, the availability of adaptation measures and adaptation costs. All of those can be affected by CAP measures such as in rural development programs. Concerning the modelled effects from the CAP reform, further research is required to analyse and explain the severe losses in gross margins for some farms. One reason may be the high historical premiums resulting from bull fattening during the reference period. Nevertheless it indicates the considerable farm level impacts of some subsidy regimes and calls for careful policy design for both the introduction and phase-out of policies.

The results on climate change impacts confirm other studies. Schönhart et al. (2013) reviewed the literature and provided spatial analysis on climate change impacts for the territory of Austria. Their results show similar impacts concerning productivity gains on grassland and moderate losses on cropland. This is expected to increase farm incomes in those

parts of Austria with currently growth-limiting temperature levels and sufficient precipitation patterns. However, such model results are based on important assumptions including sufficient autonomous adaptation by farmers, limited impacts from extreme weather events, infestation from pests and diseases, or the effectiveness of CO<sub>2</sub>-fertilization. With respect to agricultural markets, increasing productivity can even lead to income losses if its relative changes are beyond those of other producers in international markets and if disadvantageous farm structures decrease international competitiveness (cf. Hermans et al., 2010). Further research is necessary to study such market effects at the international level despite the considerable challenges with respect to data.

Quantitative analyses of complex systems require integrated modelling tools. If spatially explicit, they offer multiple opportunities to pursue inter-disciplinary research questions. In this article, we described and applied an IMF, which has been developed to analyze climate change impacts and adaptation for two Austrian case study landscapes. Its novel feature compared to other bio-economic farm models is its spatially explicit representation of fields belonging to an individual farm. This improves the representation of mechanization costs (e.g. distances of fields to the farm, size of fields), yields, and environmental outcomes. The vector-based landscape data in the IMF enables analysis of landscape structure and field scale intensity. Both are major determinants of landscape appearance and biodiversity and are impacted by climate change, as has been shown by the research results. Further research efforts include the development of model interfaces in order to analyze indirect biodiversity impacts from climate change and to include methods in landscape planning such as 3-dimensional landscape visualizations (e.g. Schauppenlehner and Amon, 2012), which provide new opportunities for the quantification of landscape values.

## References

- Aurbacher, J., Parker, P.S., Calberto Sánchez, G.A., Steinbach, J., Reinmuth, E., Ingwersen, J., Dabbert, S. (2013). Influence of climate change on short term management of field crops – A modelling approach. *Agricultural Systems* 119: 44–57.
- BMLFUW (2008). Deckungsbeiträge und Daten für die Betriebsplanung 2008. Wien: Bundesministerium für Land-, Forst-, Umwelt- und Wasserwirtschaft.
- Briner, S., Elkin, C., Huber, R., Grêt-Regamey, A. (2012). Assessing the impacts of economic and climate changes on land-use in mountain regions: A spatial dynamic modeling approach. *Agriculture, Ecosystems & Environment* 149: 50–63.
- Dono, G., Cortignani, R., Doro, L., Giraldo, L., Ledda, L., Pasqui, M., Roggero, P.P. (2013). Adapting to uncertainty associated with short-term climate variability changes in irrigated Mediterranean farming systems. *Agricultural Systems* 117: 1–12.
- Gibbons, J.M., Ramsden, S.J. (2008). Integrated modelling of farm adaptation to climate change in East Anglia, UK: Scaling and farmer decision making. *Agriculture, Ecosystems & Environment* 127: 126–134.
- Handler, F., Stadler, M., Blumauer, E. (2006). Standardarbeitszeitbedarf in der österreichischen Landwirtschaft. Wieselburg: BLT.
- Henseler, M., Wirsig, A., Herrmann, S., Krimly, T., Dabbert, S. (2009). Modeling the impact of global change on regional agricultural land use through an activity-based non-linear programming approach. *Agricultural Systems* 100: 31–42.
- Hermans, C.M.L., Geijzenborffer, I.R., Ewert, F., Metzger, M.J., Vereijken, P.H., Woltjer, G.B., Verhagen, A. (2010). Exploring the future of European crop production in a liberalised market, with specific consideration of climate change and the regional competitiveness. *Ecological Modelling* 221: 2177–2187.
- Janssen, S., van Ittersum, M.K. (2007). Assessing farm innovations and responses to policies: A review of bio-economic farm models. *Agricultural Systems* 94: 622–636.

- Kanellopoulos, A., Reidsma, P., Wolf, J., van Ittersum, M.K. (2014). Assessing climate change and associated socio-economic scenarios for arable farming in the Netherlands: An application of benchmarking and bio-economic farm modelling. *European Journal of Agronomy* 52 Part A: 69–80.
- Leclère, D., Jayet, P.-A., de Noblet-Ducoudré, N. (2013). Farm-level Autonomous Adaptation of European Agricultural Supply to Climate Change. *Ecological Economics* 87: 1–14.
- Lehmann, N., Finger, R., Klein, T., Calanca, P., Walter, A. (2013). Adapting crop management practices to climate change: Modeling optimal solutions at the field scale. *Agricultural Systems* 117: 55–65.
- Mignolet, C., Schott, C., Benoît, M. (2004). Spatial dynamics of agricultural practices on a basin territory: a retrospective study to implement models simulating nitrate flow. The case of the Seine basin. *Agronomie* 24: 219–236.
- Mitter, H., Kirchner, M., Schmid, E., Schönhart, M. (2014). The participation of agricultural stakeholders in assessing regional vulnerability of cropland to soil water erosion in Austria. *Regional Environmental Change* 14: 385–400.
- Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., von Lampe, M., Lotze-Campen, H., Mason d’Croz, D., van Meijl, H., van der Mensbrugghe, D., Müller, C., Popp, A., Robertson, R., Robinson, R., Schmid, E., Schmitz, C., Tabeau, A., Willenbockel, D., (2013). Climate change effects on agriculture: Economic responses to biophysical shocks. *PNAS* (doi/10.1073/pnas.1222465110 ; forthcoming).
- Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., Micale, F. (2011). Impacts and adaptation of European crop production systems to climate change. *European Journal of Agronomy* 34: 96–112.
- Reidsma, P., Ewert, F., Lansink, A.O., Leemans, R., 2010. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. *European Journal of Agronomy* 32: 91–102.
- Reidsma, P., Oude Lansink, A., Ewert, F. (2009). Economic impacts of climatic variability and subsidies on European agriculture and observed adaptation strategies. *Mitigation and Adaptation Strategies for Global Change* 14: 35–59.
- Schauppenlehner, T., Amon, H. (2012). Landschaftskulissen – ein GIS-basierter Ansatz zur Analyse der räumlichen Landschaftsstruktur und Bewertung landschaftsästhetischer Aspekte. In Strobl, J., Blaschke, T., Griesebner, G (eds.). *Angewandte Geoinformatik 2012. Beiträge zum AGIT-Symposium Salzburg*. Berlin and Offenbach: Herbert Wichmann Verlag, 652–661.
- Schauppenlehner, T., Schönhart, M., Muhar, A., Schmid, E. (2010). Landschaftsstruktur in der Landnutzungsmodellierung: GIS-basierte Analyse zur Bewertung von Biodiversität und Landschaftsästhetik in Kulturlandschaften am Beispiel von Streuobst. In Strobl, J., Blaschke, T., Griesebner, G (eds.). *Angewandte Geoinformatik 2010. Beiträge zum AGIT-Symposium Salzburg*. Heidelberg: Wichmann, 661–670.
- Schönhart, M., Mitter, H., Schmid, E., Heinrich, G., Gobiet, A. (2013). Integrated analysis of climate change impacts and adaptation measures in Austrian agriculture. (German Journal of Agricultural Economics; in press).
- Schönhart, M., Schauppenlehner, T., Schmid, E. (2011a). Integrated bio-economic farm modeling for biodiversity assessment at landscape level. In Flichman, G. (ed.). *Bio-Economic Models applied to Agricultural Systems*. Dordrecht et al.: Springer, 185–213.
- Schönhart, M., Schauppenlehner, T., Schmid, E., Muhar, A. (2011b). Integration of bio-physical and economic models to analyze management intensity and landscape structure effects at farm and landscape level. *Agricultural Systems* 104: 122–134.

- Schönhart, M., Schauppenlehner, T., Schmid, E., Muhar, A., 2011c. Analysing maintenance and establishment of orchard meadows at farm and landscape level applying a spatially explicit integrated modelling approach. *Journal of Environmental Planning and Management* 54: 115–143.
- Schönhart, M., Schmid, E., Schneider, U.A. (2011d). CropRota - A crop rotation model to support integrated land use assessments. *European Journal of Agronomy* 34: 263–277.
- Strauss, F., Formayer, H., Schmid, E. (2013). High resolution climate data for Austria in the period 2008–2040 from a statistical climate change model. *International Journal of Climatology* 33: 430–443.
- Williams, J.R. (1995). The EPIC Model. In Singh, V.P. (ed.). *Computer Models of Watershed Hydrology*. Colorado: Water Resources Publications, 909–1000.