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The impacts of CAP post-2013 and regional climate change on agricultural land use intensity and the environment in Austria

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We assess anticipated changes in policy and regional climate on agrarian land use development indicators in Austria for the period 2025-2040. A spatially explicit bio-economic integrated assessment quantifies impacts at 1km grid resolution in order to take into account the heterogeneity of Austrian agricultural landscapes. The impacts of the Common Agricultural Policy (CAP) post-2013 on regional producer surplus are slightly positive and payments shift from intensive to extensive production regions. The economic impact of climate change depends on changes in precipitation patterns. Policy change leads to intensification of land use in favorable cropland and grassland regions and extensification in marginal regions. Regional climate change amplifies land use intensification with increases in crop yields, e.g. in Alpine regions, and land use extensification with declining crop yields, e.g. in eastern cropland regions. Environmental indicators deteriorate at national level in all scenarios. The highly spatially diverging impacts call for more targeted policy measures.

Keywords: Common Agricultural Policy; Climate Change, Agri-environmental; Land Use; Environment
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1. Introduction

The EU Common Agricultural Policy (CAP) post-2013 and regional climate change will bring significant changes to agricultural land users in Austria in the coming decades. Changes include on the one hand the new ‘greening’ requirements for direct payments, the shift from farm-specific (historic) to regionally uniform premium levels, and changes in agri-environmental schemes, and on the other hand rising temperatures and changes in precipitation patterns which alter crop yields in magnitude and variability.

The initial period of the CAP can be characterized by increasing and modernizing agricultural production, and is thus seen as having been a major driving force of land use intensification (Zanten et al., 2014). Reforms since the 1990ies have focused on more sustainable agricultural development (e.g. the creation of pillar 2, i.e. the rural development program) by recognizing the multi-functional role of agriculture with respect to social and environmental aspects (Lowe et al., 2002). The success of these most recent reforms with respect to environmental outcomes (e.g. biodiversity, landscape diversity, balanced supply of ecosystem services from agricultural landscapes), however, is controversially debated (Schmid et al., 2007; Stoate et al., 2001; Wier et al., 2002) and scholars are skeptical if the new reform will have beneficial impacts on the environment and economic equity (Heinrich et al., 2013; Pe’er et al., 2014). Austria provides a good case study to assess these impacts, as the agri-environmental program is covering about 87% of all agricultural land (excluding Alpine meadows), 77% of all farms, and comprising ca. 30% of all agricultural policy payments under pillar 1 and 2 of the CAP in the year 2013 (BMLFUW, 2014). The most recent CAP regulations (The European Parliament and The Council of the European Union, 2013a, 2013b, 2013c) as well as the opinions of stakeholders from public administration allow us to assess likely changes in future Austrian agricultural policy.

In addition, agriculture is sensitive to climate change such that higher temperatures and CO_2 concentrations as well as changes in precipitation patterns and frequencies of extreme weather events have direct impacts on crop yields and agro-biophysical processes, which trigger farm management responses and alter environmental outcomes (Alexandrov et al., 2002; Olesen et al., 2011; BMLFUW, 2012; Mitter et al., 2014). These impacts can be substantial already until the mid of the 21st century (Thaler et al., 2012; Strauss et al., 2013b; Mitter et al., 2014; Schönhart et al., 2014) and agricultural systems are highly dependent on the adaptation potential of farmers to mitigate negative or amplify positive impacts of climate change (Leclère et al., 2013; Schönhart et al., 2014). Regional climate change should thus be taken into account by policy makers and researchers, which has been also recognized by the new CAP regulations (The European Parliament and The Council of the European Union, 2013a, 2013b, 2013c).

A few studies have already conducted ex-ante assessments of the CAP post-2013 reform, mostly with focus on the new greening measures, i.e. (i) set aside of 5% ecological focus area (EFA), (ii) crop diversification and (iii) maintaining existing permanent grassland. However, most studies do not take climate change impacts into account. The qualitative studies conducted by Lefebrve et al. (2012) as well as Westhoek et al. (2012) find that the greening of pillar 1 payments is likely to have only limited effects on farming practices, agricultural landscapes, biodiversity and GHG emissions, whereby EFAs are expected to have the most pronounced effect. The impact of crop diversification is assumed to be insignificant as most farms in the EU28 would meet this criterion already today. The maintenance of permanent grassland could keep extensive production areas from being abandoned, but the final regulation (No 1307/2013 Article 45/2), which had not been available to these studies yet, seems to differ little from the original cross compliance requirement for permanent grassland maintenance in the period 2007-2013 (No 796/2004 Article 3/2)[1]. Van Zeijts et al. (2011) provide a detailed spatially explicit integrated assessment study for the EU27 on the CAP 2014-2020 based on the EU communication document "The CAP towards 2020" (European Commission, 2010). They find that the pillar 1 greening improves farmland biodiversity in the EU27 and in Austria compared to a continuation of the CAP 2007-2013, although biodiversity is expected to decline in absolute numbers. GHG emissions decrease, but not significantly. Notably, their results are strongly driven by the assumption that funding for agri-environmental measures increases. This, however, is not indicated by the EU's final regulation for the period 2014-2020. Comparing the pre-allocations for the rural development program 2007-2013 with 2014-2020[2] shows that the available volumes for subsidies increase with nominal prices by +6% and +1% for the EU-25 and Austria, respectively, but accounting for inflation indicates a decrease of -9% and -14% in real terms, respectively[3]. Regarding economic impacts, Solazzo et al. (2014) find that the two greening requirements crop diversification and EFA can lead to losses in gross margins for arable farms and the tomato sector in Italy using a regional farm model. In contrast, van Zeijts et al. (2011)

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[1] For example, in regulation EC 769/2004 permanent grassland shall not decrease by 10% and in regulation EU 1307/2013 by 5%. In addition, a previous proposal by the European Commission (2011) put the responsibility on farmers (Article 31/1) whereas in the final regulation EU 1307/2013 it is again the member state that is responsible for ensuring the maintenance of permanent grasslands.

[2] See Regulation (EU) No 1305/2013 for the pre-allocations for the period 2014-2020 and the Commission Decision 2006/636/EC with regard to the Council Regulation (EC) No 1689/2005 for the pre-allocations for the period 2007-2013.

[3] For the calculation of real prices we used the Harmonized Index of Consumer Prices (2005 = 100) from EuroStat. Pre-allocations for 2007-2013 are given in 2006 prices (i.e. HICP of 102.2 and 101.7 for EU and Austria, respectively) and Pre-allocations for 2014-2020 are given in 2013 prices (i.e. HICP of 120.1 and 120.5 for EU and Austria, respectively).

employ the partial equilibrium model CAPRI and find that average farm incomes in the EU can increase despite production decreases if commodity prices rise as a response. According to their spatial results, income in Austria declines in intensive arable regions but increases in extensive grassland areas in the Alpine regions. There findings generally indicate a shift of payments from intensive to extensive farms, thus providing a better link between payments and provision of public goods such as biodiversity. In addition, Matthews et al. (2013) find that the transition of historical to regional area-based direct payments also shifts policy support from intensive to extensive production regions[4].

Regarding regional climate change impacts several integrated agronomic studies have already assessed the vulnerability of croplands to climate change in Austria until the mid of the 21st century (Alexandrov et al., 2002; Klik and Eitzinger, 2010; Thaler et al., 2012; Strauss et al., 2013b). Although these studies analyse and suggest alternative agronomic adaptation measures to reduce adverse impacts on crop yields and environment (e.g. soil conservation to reduce soil erosion and retain soil water content), they do not include any economic and policy aspects. Schönhart et al. (2014), however, show in a first national agricultural impact and adaptation study that autonomous adaptation by profit-maximizing farmers can lead to mostly positive economic outputs at regional to sector scale until the mid of the 21st century. They also reveal that economic and environmental impacts as well as the choice of adaptation measures differ substantially across NUTS3 regions in Austria. Given these regional differences, it is important to further analyse agricultural impact chains at high spatial resolution as well as to evaluate trade-offs and synergies between economic and environmental effects from autonomous farm adaptation.

This article thus aims to quantify the impact of CAP post-2013 and regional climate changes on agricultural land use choices, as well as land use development indicators in Austria for the period 2025-2040. We apply a state-of-the-art spatially explicit integrated assessment in order to quantify the impacts at high spatial resolution (1km). The integrated assessment comprises of the statistical climate model ACLiReM (Strauss et al., 2013a), the bio-physical process model EPIC (Izaurralde et al., 2006; Williams, 1995), the agronomic crop rotation model CropRota (Schönhart et al., 2011b) and the bottom-up land use optimization model for the agricultural and forestry sector PASMA$_{[grid]}$ (Kirchner et al., in press; Schmid et al., 2007). Integrated assessments shall support the development of targeted farm adaptation strategies as well as the coordination of autonomous and policy induced adaptation of land use systems and are thus widely applied (Audsley et al., 2006; van Meijl et al., 2006; Schneider et al., 2007, 2011; Henseler et al., 2009; Schönhart et al., 2014; Briner et al., 2012; Strauss et al., 2012). However, despite

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[4] Van Zeijts et al. (2011) already consider the regional area-based payments in their baseline scenario. Their findings thus only relate to changes in the greening measures and agri-environmental schemes.

the advances in integrated assessments and numerous applications (Laniak et al., 2013), multi-regional integrated assessments at high spatial resolution are still heavily required to derive robust and sufficiently stratified spatial results acknowledging a broader range of heterogeneities and uncertainties.

The remainder of the article is structured as follows: In section 2 we introduce the methodological framework of our integrated assessment, provide detailed insights into the PASMA$_{[grid]}$ model, model interfaces, and major data sources. Section 3 elaborates on the scenarios and section 4 presents our scenario results. A critical discussion of our results and methodological approach is provided in section 5. The article ends with concluding remarks and policy recommendations (section 6).

2. Method

2.1. Integrated Assessment

The methodological framework of our integrated assessment is depicted in Figure 1 and follows similar frameworks developed by Schönhart et al. (2011a, 2014), Kirchner et al. (2015), Schmidt et al. (2012) and Stürmer et al. (2013). It builds on the idea that it is essential to explore the heterogeneity of drivers (e.g. climate change and policies) and pressures (e.g. water withdrawals or fertilization) of land use change and management choices.

In the framework, the CropRota model derives typical crop rotations at municipality level, taking into account observed land use and agronomic constraints (Schönhart et al., 2011b). The statistical climate model ACLiReM uses regressions and bootstrapping methods in order to forecast temperature trends and project precipitation patterns in Austria until 2040 (Strauss et al., 2013a). It provides daily weather data at a spatial resolution of 1km. Both models provide input to the biophysical process model EPIC (Williams, 1995; Izaurralde et al., 2006). EPIC simulates crop yields and environmental outcomes (e.g. nitrogen and phosphorus emissions, SOC content, sediment losses) of alternative crop production management systems for different climate-site-crop regimes at a spatial resolution of 1km. In EPIC, climate data is provided by ACLiReM and CropRota provides data on typical crop rotations. Hence, outputs are differentiated by site-specific topographical, soil, and climate characteristics as well as by agronomic measures (e.g. crop rotations, fertilization intensity, irrigation and soil management measures). Finally, the bottom-up economic land use optimization model PASMA$_{[grid]}$ integrates the crop yield data in order to derive optimal geo-referenced production portfolios of profit maximizing farmers. Other environmental indicators from EPIC, e.g. nutrient emissions and SOC content, are used to assess the external effects of production choices.

2.2. PASMA$_{[grid]}$

PASMA$_{[grid]}$ is a linear programming model. It builds on the Austrian agricultural sector model PASMA (Schmid et al., 2007; Schmid and Sinabell, 2007), but represents in more detail the structural and environmental heterogeneity of the agricultural sector. Agricultural land use includes all cropland, grassland, Alpine meadows and permanent crops (i.e. wine, fruit orchards and short rotation coppice) at 1km resolution. Livestock production is modeled at NUTS3 level including feed and fertilizer balances. PASMA$_{[grid]}$ has already been applied in a regional case study application on the supply of biomass to support regional energy autarky concepts (Schmidt et al., 2012), as well as in a large scale integrated assessment to quantify ecosystem services trade-offs and synergies for different policy and climate change scenarios (Kirchner et al., 2015). This article provides a thorough introduction of PASMA$_{[grid]}$ with focus on its potential to elicit important spatial aspects of autonomous adaptation by farmers to policy and climate change.

Figure 2 gives an overview of the model by displaying endowments and constraints, the objective function, and production and management choices. The regional producer surplus (RPS) is maximized for each NUTS3 region subject to natural, structural and regional farm resource endowments (e.g. amount of cropland or livestock housing capacity available in a region) as well as technical restrictions (e.g. feed and fertilizer balances). To avoid over-specialization observed land use and livestock activities provide boundaries and compositions from which the model chooses optimal convex combinations (McCarl, 1982). PASMA$_{[grid]}$ is a bottom-up supply model under the small country assumption, i.e. commodity prices are exogenously given and market feedbacks are not accounted for endogenously. PASMA$_{[grid]}$ optimizes at independent points in time typical to comparative static approaches.

Choices on agrarian land uses and crop management variants depend on factors such as commodity prices, production costs, subsidies, yields and nutritional value for livestock activities. In this study, the model can chose among four mutual exclusive fertilizer management variants: rainfed agriculture with (1) high, (2) moderate, and (3) low fertilization intensities on cropland and grassland, and (4) irrigated agriculture with high fertilization intensity on cropland. The level of fertilization intensities are based on public crop management guidelines (BMLFUW, 2006). On cropland these fertilizer variants can be combined with three mutual exclusive soil management variants: (a) conventional tillage (i.e. mouldboard plough with 15% crop residue on soil surface before planting); (b) reduced tillage (i.e. light disc or chisel plough with 15–30% crop residue on soil surface before planting), and (c) reduced tillage including winter cover crops are considered.

The model also includes a GHG accounting module that resembles the accounting methods of the Austrian National Inventory Report (AIR) for GHG emissions of the agricultural sector (Anderl et al., 2014). The PASMA$_{[grid]}$ production activities relevant for GHG emissions (e.g. fertilizer use, legume area, livestock production) are used in the GHG module to calculate total GHG emissions for each scenario. Total GHG emissions from agriculture comprise of (1) enteric fermentation (ca. 43%), (2) manure management (ca. 16%), (3) soil emissions (ca. 41%), and (4) field burning (less than 1%). Almost all necessary GHG activities can be represented by PASMA$_{[grid]}$ except the distribution and usage of different manure management systems and field burning, which are therefore kept constant. Emissions from changes in imported feed are not considered. Changes in local soil carbon contents are estimated in EPIC. The GHG module has been successfully validated for the reference year 2008 using both AIR production activity data (difference of -1% to the official total GHG emissions from the agricultural sector) as well as PASMA$_{[grid]}$ production activities (difference of -5%). The highest discrepancies between PASMA$_{[grid]}$ activities and AIR occur due to different livestock categorization.

2.3. The EPIC and PASMA$_{[grid]}$ Interface

The interface between the spatially stratified biophysical simulation data from EPIC and PASMA$_{[grid]}$ utilizes the concept of homogeneous response units (HRUs) (Schmid, 2007; Stürmer et al., 2013). An HRU shares equal natural characteristics such as elevation, slope and soil type and allows proper aggregation of impacts in bottom-up economic land use optimization models. Thus, PASMA$_{[grid]}$ integrates heterogeneous biophysical impact and endowment data (i.e. land qualities with different crop yields and environmental outcomes) at the intersection of HRU and municipality boundaries leading to unique geo-referenced spatial units of 1km. Optimal land use and management choices are thus derived for each spatial unit considering the opportunity costs of agricultural land use and livestock production. Hence, information on land endowments, biophysical impacts, and opportunity costs is available at higher spatial resolution than in many other studies at regional to national scale (e.g. Schönhart et al., 2013). It allows better representation of heterogeneities in farming responses and localisation of hot-spots.

2.4. Major Data Sources

Data on resource endowments and observed land use are obtained from the Integrated Administration and Control System (IACS), the digital soil map of Austria (Federal Research and Training Centre for

Forests, Natural Hazards and Landscape, BFW), the digital elevation map (Federal Office of Metrology and Surveying, BEV), the farm structure survey, and the Austrian Farm Accountancy Data Network (FADN). Data on production costs are estimated from standardized gross margin tables for Austrian agriculture (BMLFUW, 2008) and standardized farm labour estimates. Product prices are taken from Statistics Austria and price forecasts from the OECD-FAO agricultural outlook (OECD/FAO, 2013). Policy scenarios including assumptions on the CAP reform result from a stakeholder process and official documents.

3. Scenarios

We include two policy scenarios. The baseline scenario (*BASELINE*) depicts policy payments and requirements from the reference year 2008 and thus the CAP period 2007-2013. The CAP post-2013 scenario (*REFORM*) takes into account the upcoming changes for the new policy period and information obtained from a stakeholder dialogue with members from the Austrian Federal Ministry of Agriculture on likely changes in Austria's agri-environmental program. We assume that both policy scenarios are continued until the period 2025-2040. This allows us to take into account more pronounced mid-term regional climate change impacts. Changes in prices and costs are obtained from OECD/FAO (2013) but kept constant across the scenarios in order to single out the policy impacts.

Table 1 shows how CAP post-2013 has been operationalized in $\text{PASMA}_{\text{[grid]}}$ compared to the *BASELINE* scenario. Changes include the shift of direct payments from the historical model towards the regional model, a reduction of payments for less favored areas, organic farming and sowing of cover crops, as well as the abolishment of the widely applied agri-environmental measure 'environmentally friendly management' of the Austrian agri-environmental program 2007-2013 (the $\text{PASMA}_{\text{[grid]}}$ equivalent is the management option 'medium fertilizer intensity'). Furthermore, we include the abolishment of the milk quota, suckler cow premium and some remaining crop premiums (e.g. durum wheat, protein and energy crops). Regarding the new greening measures, we consider the 5% requirement of EFA by assuming that 5% of the regional arable crop share mix has to comprise of EFA, which is equivalent to fallow land in our land use model. The crop diversity requirement is omitted as $\text{PASMA}_{\text{[grid]}}$ is a regional and not a farm level model, but FADN data indicates that most farms would meet this requirement in Austria, as is the case for most of Europe (Lefebvre et al., 2012; Westhoek et al., 2012). To represent the new greening as well as the current cross-compliance requirement (see section 1) our model does not allow conversion of permanent grassland to arable land in both scenarios.

We link the policy scenarios to biophysical data for the observed period 1990-2005 (*Past*) as well as four climate change scenarios (see Table 2) with identical temperature trends (1.5°C) but varying assumptions on precipitation (Strauss et al., 2013a). The uncertainty in precipitation changes is represented by increases (*High*), seasonal shifts (*Shift*) and decreases (*Low*) in precipitation as well as assuming similar distribution as in the past (*Similar*). Bio-physical impacts are averaged for both periods. Hence, we provide a plausible range of possible future climates for the period 2025-2040.

The scenario *REFORM-Past* thus assesses solely policy impacts in the period 2025-2040, whereas the remaining scenarios (*REFORM-High/Similar/Shift/Low*) further take into account regional climate change.

4. Results

4.1. Land Use Choices

Figure 3 details the change in the shares of the land use management options considered in $\text{PASMA}_{[\text{grid}]}$ at national level. It indicates that the share of medium fertilizer intensity declines substantially in all *REFORM* scenarios between 40% in *REFORM-Similar* and 45% in *REFORM-Past* due to the abolishment of the agri-environmental subsidy for this measure. At aggregate level, most of this loss is compensated by an increase in high fertilizer intensity. Nonetheless, some farmers opt to switch from medium to low fertilizer intensity (i.e. the equivalent to the Austrian agri-environmental measure 'renunciation of agro-chemical inputs'), as payments for this measure are still in place in our policy scenarios. Regional climate change further enhances land use intensity due to (i) its positive impact on crop yields and thus higher nutrient requirements by plants, as well as (ii) autonomous adaptation towards more intensive production systems.

The decrease in payments for sowing winter cover crops leads to a considerable decline in the share of cover crops at national level, e.g. -48% in *REFORM-Past* (see Figure 3). Both standard and reduced tillage increase as a response but there is a difference between the regional climate change scenarios. As winter crops can compete with the consecutive crop for water resources, their share declines with warmer temperatures (*REFORM-Similar*/*Shift*) or less precipitation (*REFORM-Low*). The increase in annual precipitation sums in *REFORM-High* seems to compensate for the increase in evapotranspiration due to higher temperatures. Furthermore, standard tillage becomes more competitive under the regional climate change scenarios than reduced tillage.

Figure 4 illustrates the importance of accounting for regional heterogeneity. It shows how fertilizer intensity on utilized agricultural area (UAA) changes in the *REFORM-Past* scenario compared to the *BASELINE* at 1km resolution. UAA with medium fertilizer intensity declines in most areas, but the strongest decreases are modelled on arable land along the Danube flatlands in the North-West (i.e. Upper Austria and western Lower Austria). These areas also show a stronger change from medium to high fertilizer intensity than from medium to low. To the contrary, intensive grassland areas in the Alpine region show a tendency to switch from medium to low fertilizer intensity due to policy changes. This indicates that different regions face substantially different opportunity costs with respect to land use management options.

EFAs increase substantially in all scenarios between 17% and 18% mostly at the cost of wheat (-1%), corn (-2%) and forage crops (-4%). We further find small increases for vegetables (1%) and protein crops (+2%). Regional climate change does not have significant impacts on cultivar choices until 2040 in the model.

4.2. Land Use Development Indicators

The impact of CAP post-2013 as well as regional climate change on selected land use development indicators is shown in Figure 5. Agricultural producer surplus increases in *REFORM-Past* by 3% at the aggregated national level. The abolishment of the remaining coupled payments as well as the decrease in payments for less favored areas (-15%) and agri-environmental measures (-29%) is more than counterbalanced by both the increase in direct payments (+15%), due to the shift from the historical to the regional model, and by increasing revenues from milk production, due to increased sales because of the abolishment of the milk quota. Regional climate change leads to additional increases in *REFORM-Shift*/*Similar*/*High*. In *REFORM-Low* the impact is still positive compared to the *BASELINE* (+2%) but lower than in *REFORM-Past*, indicating a negative economic impact in case of substantial decreases in annual precipitation sums. The positive economic impacts of regional climate change until 2040 come from increases in agricultural yields, as higher temperatures are beneficial in many humid Austrian regions until 2040. Regions that can be negatively affected are situated in the eastern semi-arid cropland, southern Burgenland und south-east Styria, where water can become a limiting factor, especially in *REFORM-Low*.

Biomass production does not change significantly in *REFORM-Past* (+1%), but large gains are obtained in the regional climate change scenarios (between 4% in *REFORM-Low* and 11% in *REFORM-High*). We observe a strong difference between biomass production on cropland, grassland and Alpine meadows in our model results. Biomass production on cropland is only positively affected in *REFORM-Past* and *REFORM-High* (both +1%), but declines slightly in *REFORM-Similar* (-1%) and *REFORM-Shift* (-2%) and considerably in *REFORM-Low* (-7%). Large increases in forage yields from both grasslands and Alpine meadows compensate for these losses. These land use types are usually situated in colder and more humid areas and can thus benefit from higher temperatures. For example, forage yields from grasslands can increase between 25% in *REFORM-Low* and 30% in *REFORM-High*.

Figure 6 highlights regional differences in economic impacts at NUTS3 level. Regional agricultural producer rent can increase in grassland dominated regions in the Alpine West across all scenarios. Contrarily, significant declines in producer rent can occur in the East, where many intensive cropland areas are situated and water can become a limiting factor under climate change. The main driving forces behind the regional differences are (i) the shift of direct payments from the historical to the regional model, as historical payments have been higher in intensive production regions and (ii) the different impacts of regional climate change on crop and forage yields. To sum up, payments shift from intensive to more extensive production areas. Regional climate change intensifies these economic impacts due to its positive effect on yields in Alpine areas (and a successful utilization of additional grassland yields in livestock production), as well as due to its negative impacts in the East.

In almost all scenarios, environmental indicators deteriorate at national level (see Figure 5). The increase in UAA with high fertilizer intensity leads to more nitrogen and phosphorous application rates in *REFORM-Past* by about 2%. This impact is markedly enhanced by the regional climate change scenarios (between +3% and +10% for nitrogen and +5% and +12% for phosphorous). Most of this boost is driven by higher nutrient demand by crops due to higher yields (as can be seen by similar changes for biomass production) as well as by autonomous adaptation measures. *REFORM-Past* further leads to decreases in topsoil organic carbon (SOC) by ca. 2% mainly due to the decline in winter cover crops. The regional climate change scenarios have different impacts on SOC. A negative impact on SOC is reinforced in *REFORM-High* (-5%) due to higher temperatures (i.e. increasing mineralization) and soil erosion. More crop residue due to higher crop yields can alleviate some of the impact in *REFORM-Similar* (-1%) and *REFORM-Shift* (-0.3%). Drier soil conditions and less soil erosion even lead to increases in SOC in *REFORM-Low* (+2%). Regarding GHG emissions, the new CAP reform seems to fail in its objective to contribute to climate change mitigation as GHG emissions increase by more than 3% in *REFORM-Past*, which mainly comes from increased fertilizer usage and larger cattle herds in Austria. Regional climate change increases this impact in all but the *REFORM-Low* scenario.

The heterogeneous impact of the climate change and policy scenarios is again demonstrated in Figure 7 for the case of nitrogen fertilizer. In *REFORM-Past* we see increases mostly in intensive cropland production regions in the North and East of Austria, although some extensive production regions in the eastern Alpine foreland also increase fertilizer application rates. However, fertilizer application rates decline for most of the Alpine region, which is usually dominated by extensive forage production (except for the major valleys). A markedly different picture can be seen for the four regional climate change scenarios. Here, increases in forage yields lead to much higher fertilizer application rates in intensive as well as extensive grassland regions. Decreases are modelled for some intensive cropland regions, especially in *REFORM-Low*, along the Danube, in the very East, as well south-east Carinthia and Styria.

5. Discussion

5.1. General Impacts

An integrated assessment has been conducted to analyse policy and climate change impacts and effects of autonomous adaptation by profit-maximizing farmers on producer rents and environmental outcomes. It shall guide policy-induced adaptation. For example, increasing fertilizer use is usually associated with declining biodiversity (Schmitzberger et al., 2005; Niedrist et al., 2009; Kirchner et al., 2015) and may result in higher nitrogen emissions.

The model results suggest spatially heterogeneous impacts of CAP post-2013 on the intensity of agrarian land use and its accompanying environmental effects. The geo-referenced outputs of $\text{PASMA}_{[\text{grid}]}$ indicate that increases in high fertilizer intensity take place mainly in regions with favorable conditions for crop production (e.g. Danube flatlands, south Styria), but further enhances the extensification of agrarian land use in more marginal production areas such as the Alps. Therefore, the payment for ‘medium fertilizer intensity’ (which is abolished in the *REFORM* scenario) can in some regions lead to more intensive land use if it diverts land use choices from low to medium fertilizer intensity. This indicates that agri-environmental payments should be designed carefully, taking into account the different opportunity costs across the agricultural landscape. Furthermore, if subsidies for winter cover crops are actually reduced, this will likely lead to more intensive soil management on cropland, on average.

In addition, our results show the importance of considering the impact of regional climate change as it may further stimulate the intensification of agrarian land use, i.e. increasing fertilizer rates or soil management intensities in the next decades. CAP reforms beyond 2020 should take such results into account. Model results suggest that most of the increase in fertilizer use due to regional climate change follows from increased nutrient requirements due to higher yields at higher altitudes, whereas the increases in fertilizer use on Alpine foreland and major Alpine valleys (e.g. in Upper and Lower Austria as well as Carinthia) appear amplified by adaptation. To the contrary, fertilizer use in the East decreases substantially because of both lower yields and the adoption of low fertilizer management regimes. Intensification in the regional climate change scenarios is the result of higher marginal value products of inputs such as fertilizers. It also leads to higher opportunity costs of extensive land use and puts pressure on participation in agri-environmental schemes. The productivity gains from average climate change are similar to increasing market prices and challenge the efficient design and affordability of future agri-environmental schemes.

5.2. Comparison of results

5.2.1. CAP post-2013

Our results for the *REFORM-Past* scenario, which assesses policy impacts only, reflect to some extent the findings by Lefebrve et al. (2012), Westhoek et al. (2012) and van Zeijts et al. (2011). The greening measures crop diversification and maintaining permanent grasslands could per se not have any impact in our integrated assessment, as we did not account for the former and assumed that changes between the policy scenarios are the same with respect to the later (see discussion in the introduction). The requirement for 5% EFA does lead to a strong increase of fallow land in Austria but it seems too low to significantly affect environmental indicators such as fertilizer rates, GHG emissions and topsoil organic carbon. Nonetheless, it is likely that EFAs could have a small but positive impact on vascular plant diversity (Kirchner et al., 2015). Biodiversity could further profit from more extensive agrarian land use in the Alpine regions.

Although we find a shift of policy payments from intensive to marginal production regions as van Zeijts et al. (2011) do, the driving forces behind these shifts are different. In van Zeijts et al. (2011) it is the increase in agri-environmental payments that leads to the shift in payments, as they already assume regionalization of direct payments in their baseline scenario. In our case the driving force behind the shift is the actual regionalization of direct payments, which is in accordance with the results of Matthews et al. (2013).

Van Zeijts et al. (2011) find an increased uptake of agri-environmental measures in extensive grassland regions due to higher agri-environmental payments. While this is not the case in our scenario assumptions, we do find that those areas remaining in the agri-environmental program shift towards even more extensive forms of production. As we account for the opportunity costs of production choices in heterogeneous agricultural landscapes, we are able to show where it becomes more profitable to switch to low fertilizer intensity than to high fertilizer intensity on marginal grassland areas in the Alpine regions (see also discussion in section 5.1 and example Figure 4).

As expected due to the other studies (Lefebvre et al., 2012; van Zeijts et al., 2011; Westhoek et al., 2012) we only find small impacts on GHG emission. But contrary to their results and expectations GHG emissions increase in our modeling approach in Austria. These results are driven by increasing fertilizer usage, due to less agri-environmental payments, and increasing cattle herds, due the abolishment of the milk quota regime.

Notably, none of the studies above considered the impacts of regional climate change. This seems to be a shortcoming as our results show that regional climate change scenarios can have substantial impact on policy relevant land use development indicators, e.g. agricultural producer rent and land use intensity. Such effects may be less important in the upcoming period but are relevant beyond 2020. Future CAP reforms should take regional climate change impacts and adaptation pressures into account to increase resilience of the farmer sector and better meet societies' expectations on sustainable land use.

5.2.2. Regional Climate Change Impacts

The results of the scenarios that consider regional climate change reflect to a large extent findings in previous studies, e.g. the potential negative impacts on crop yields in the eastern pannonian crop production regions (Alexandrov et al., 2002; Kirchner et al., 2012; Strauss et al., 2012; Thaler et al., 2012), SOC impacts (Smith et al., 2005), and increases in forage yields on Alpine grasslands (Smith et al., 2005; Henseler et al., 2009; Briner et al., 2012; Schönhart et al., 2014).

With respect to economic impacts, PASMA$_{[grid]}$ outputs confirm the direction of results presented by Schönhart et al. (2014) at NUTS3 level and by Leclère et al. (2013) at country level. While both studies take into account similar adaptation measures by farmers, differences may accrue due to different climate change scenarios (scenarios in both studies are based on global circulation models and regional downscaling), different climate periods (2031-2050 and 2071-2100, respectively), and model resolution (NUTS3 and Austria at country level, respectively). Some studies further support our findings that adaptation to climate change in Austria may lead to (1) a general move towards more intensive production (van Meijl et al., 2006; Leclère et al., 2013; Schönhart et al., 2014) as well as (2) regional differences in land use intensity changes (Audsley et al., 2006; Henseler et al., 2009). The latter impact has also been observed in a regional case study in Switzerland (Briner et al., 2012). In contrast to Briner et al. (2012)

and Henseler (2009) we do not find any significant land abandonment in Alpine areas. Except for Briner et al. (2012), who provide a regional case for Switzerland with a spatial resolution of 1ha, most of the studies that account for autonomous adaptation were modelled at a much coarser resolution than $\text{PASMA}_{[\text{grid}]}$ (e.g. NUTS3 or country level). The climate change impacts on crop yields in our study have been averaged over a 15-yrs period. Impacts from certain extreme events (e.g. heavy rainfalls within a single day) or indirect impacts of climate change, such as from changing pest and disease pressures, are not considered in $\text{PASMA}_{[\text{grid}]}$ so far and are subject to future research.

5.3. Effects of Model Structure and Assumptions

We did not find strong responses in modelled crop choices. Lack of responsiveness with regard to crop choices may be partly the result of the model set-up. The solution space is limited to observed crop mixes at NUTS3 level. This approach helps to avoid unrealistic corner solutions typical to linear programming but can be too restrictive with regard to alternative crop choices in a region (e.g. it does not allow for the adoption of crops that have not been used in the region before).

$\text{PASMA}_{[\text{grid}]}$ results are further limited by its availability of adaptation measures. Although important measures such as the choice of crops, fertilizer use, soil management, and land allocation are included, some others have not been considered yet either due to lack of knowledge (e.g. new land management techniques and crop breeds) or because they are outside of our modelling boundaries (e.g. changes in the infrastructure, seasonal weather forecasting, crop and weather insurance). Our results may thus underestimate the potential of farmers to adapt to policy and climate change (for further discussion see also Schönhart et al. (2014)).

Our model results are strongly driven by the underlying policy assumptions. Importantly, changes in agri-environmental programs will strongly influence the environmental outcomes of CAP post-2013. While the assumptions of van Zeijts et al. (2011) might have been too optimistic (i.e. increases in agri-environmental payments), the assumptions of our stakeholders might have been too pessimistic. The actual real decrease in funding for agri-environmental measures in Austria will most likely be far smaller than expected by our stakeholders and thus in our scenario assumptions. The current draft of the Austrian agri-environmental program (AMA, 2015) shows that the agri-environmental measures and requirements have changed to some extent and that nominal payments have remained unchanged in most cases, although payments for specific measures show both nominal increases and decreases. Notably, the widely adopted measure ‘environmentally friendly management’ has been thoroughly revised. It now serves as an equivalent to the greening requirement and it does not include the requirement to stay below the officially recommended fertilization rates anymore. Hence, while we are thus likely to overestimate the negative impact of CAP post-2013 on land use intensity and environmental indicators, the general trend should not be much different if new assessments are carried out once the Austrian agri-environmental program is officially adopted by the European Commission.

Furthermore, uncertainties related to input data, parameters and model simulations have to be acknowledged. Integrated modelling frameworks can both increase uncertainty, e.g. if uncertainty is passed on along a cascade of model linkages (Wilby and Dessai, 2010) and reduce uncertainty if advanced models substitute simple parameter assumptions. The impact of parameter uncertainty may be approached by means of Monte-Carlo simulations and subsequent sensitivity analyses (e.g. Höltinger et al., 2014; Kirchner and Schmid, 2013; Schmidt et al., 2012). But the larger the modelling framework and the larger the individual models, the more difficult and resource intensive it becomes to conduct extensive sensitivity analyses. Currently, a programming structure is being developed to conduct such sensitivity analyses for $\text{PASMA}_{[\text{grid}]}$ in a feasible manner. With regard to the uncertainties of possible futures, scenario analyses are seen as a useful tool in providing plausible narratives (Sohl and Claggett, 2013).

Given these constraints, our results still illustrate regions where autonomous adaptation could both amplify economic-environmental trade-offs – in case higher fertilizer intensity becomes more profitable – and reduce economic-environmental trade-offs – in case low fertilizer intensity becomes more profitable.

6. Conclusion

Our findings suggest that CAP post-2013 could, on average, lead to more intensive agrarian land use and to negative impacts with regard to environmental indicators such as fertilizer application rates, topsoil organic carbon and GHG emissions. Policy payments seem to shift from eastern cropland to western grassland dominated production regions. Given the assumed changes in the Austrian agri-environmental program these findings underline the concern of scholars that the new CAP reform may fail to deliver better environmental outcomes than its predecessor.

We further show that not considering regional climate change would considerably underestimate the change in land use development indicators. Regional climate change and farm adaptation measures can amplify economic-environmental trade-offs. In the absence of targeted policies, environmental impacts of autonomous adaptation such as intensification of agricultural production likely fail to deliver socially optimal outcomes. Consequently, intensification by increasing fertilizer and soil management should be limited by policies, if environmental costs are expected to increase above their benefits. In contrast, higher crop yield potentials through climate change should be realized if environmental impacts are low. The geo-referenced results of our integrated assessment demonstrate the importance of considering spatial heterogeneities with regard to policy and climate change impacts, opportunity costs in production and agri-environmental participation. Hence, they allow identification of potential environmental hot-spots and can thus support the design of regionally targeted policy responses. This may include the support of targeted agri-environmental schemes in regions with high intensification pressures (e.g. Alpine foreland), or policies on conservation tillage in regions with high losses in SOC or soil erosion from changing precipitation patterns.

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Tables and Figures

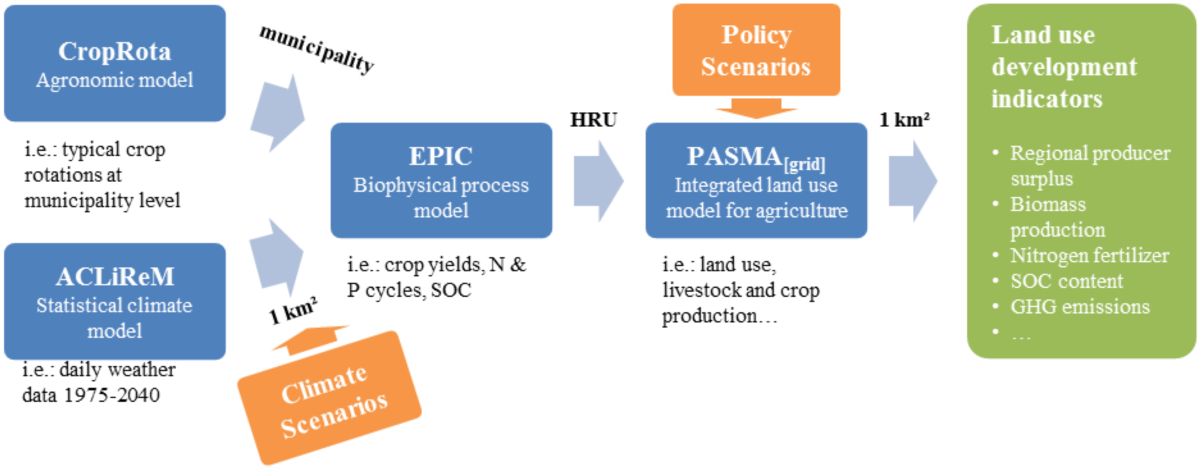

Figure 1: The methodological framework for quantifying policy and climate impact chains in Austrian agriculture (own)

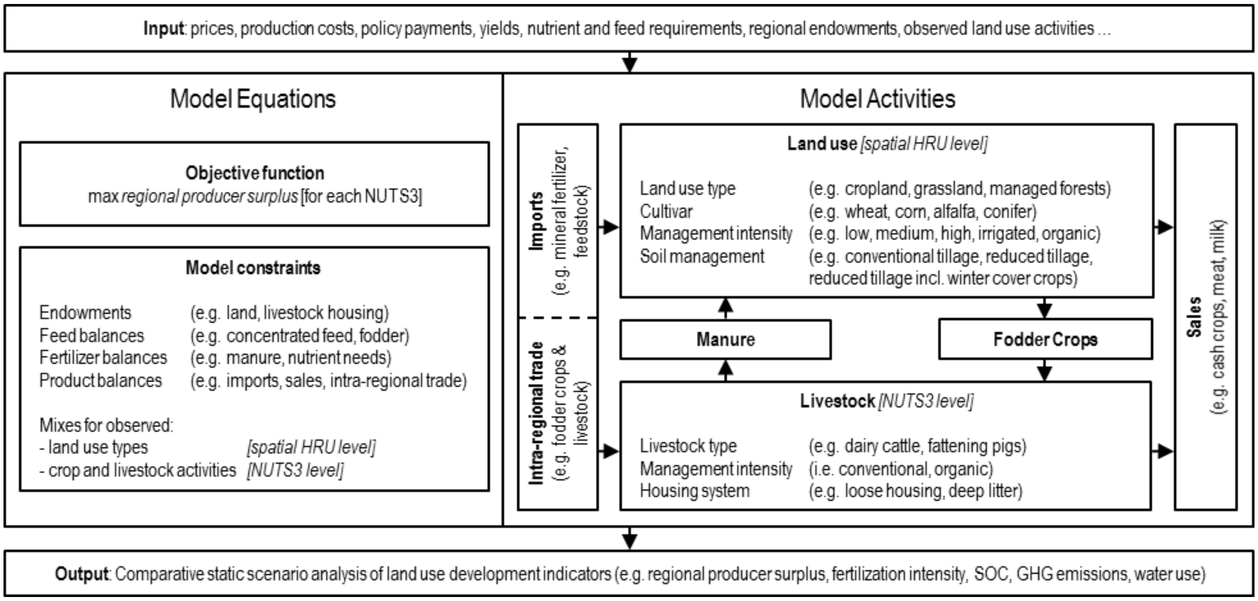

Figure 2: The model structure of PASMA[grid].

Table 1: Difference between CAP post-2013 and the reference year 2008 in PASMA$_{[grid]}$.

Model Parameter	***REFORM* vs. *BASELINE***
Direct payments	Introduction of regional uniform premium levels: €291 ha^{-1} for arable land and intensive grassland €73 ha^{-1} for extensive grassland
Payments for less favored areas	-15%
Payments for medium fertilizer intensity	Abolished
Payments for sowing cover crops	-25%
Payments for organic farming	-25€ ha^{-1}
Milk quota	Abolished
Suckler cow premium	Abolished
Ecological focus areas	5%

Table 2: The climate change scenarios considered in our analysis.

Scenario	**Period**	**Temp.**	**Precipitation**
Past	1990-2005	observed	observed
High	2025-2040	+1.5°C	+20% annual precipitation sums
Similar	2025-2040	+1.5°C	assuming similar distributions of precipitation sums compared to the past
Shift	2025-2040	+1.5°C	20% decrease in summer precipitation sums and respective increase in winter
Low	2025-2040	+1.5°C	-20% annual precipitation sums

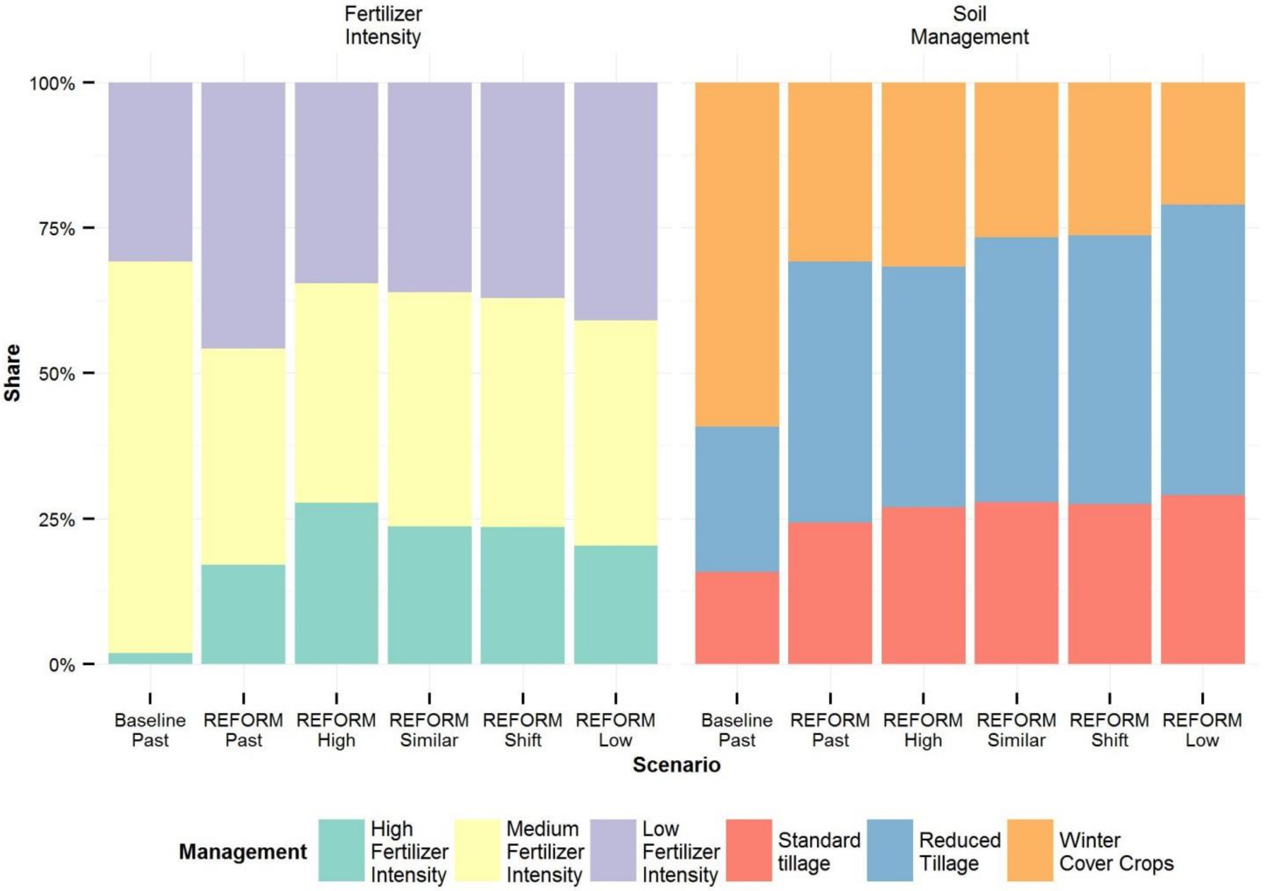

Figure 3: Share of fertilizer, tillage, and cover crop management systems at national level for all scenarios.

Note: Fertilizer intensity relates to all agricultural land, whereas soil management only to cropland.

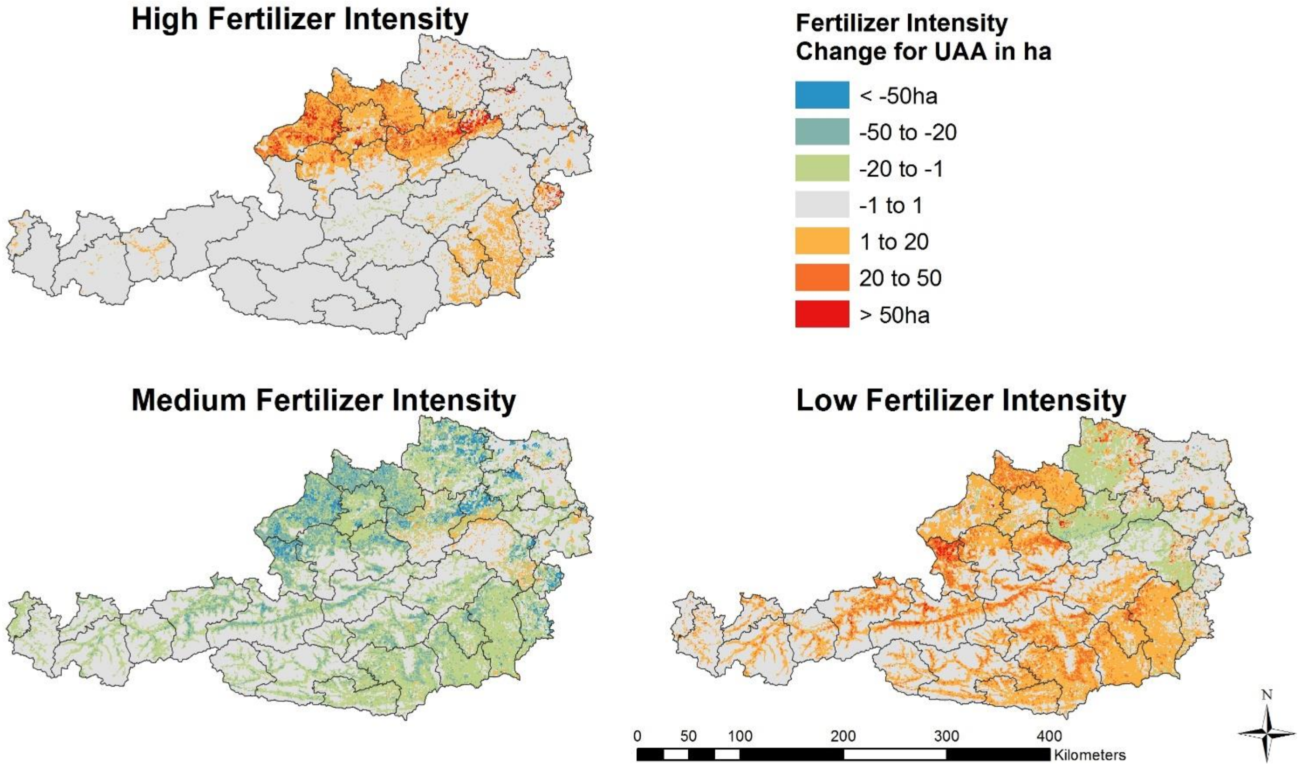

Figure 4: Change in fertilizer management in the REFORM-Past scenario compared to the BASELINE at 1km resolution. Note: UAA = Utilized Agricultural Area

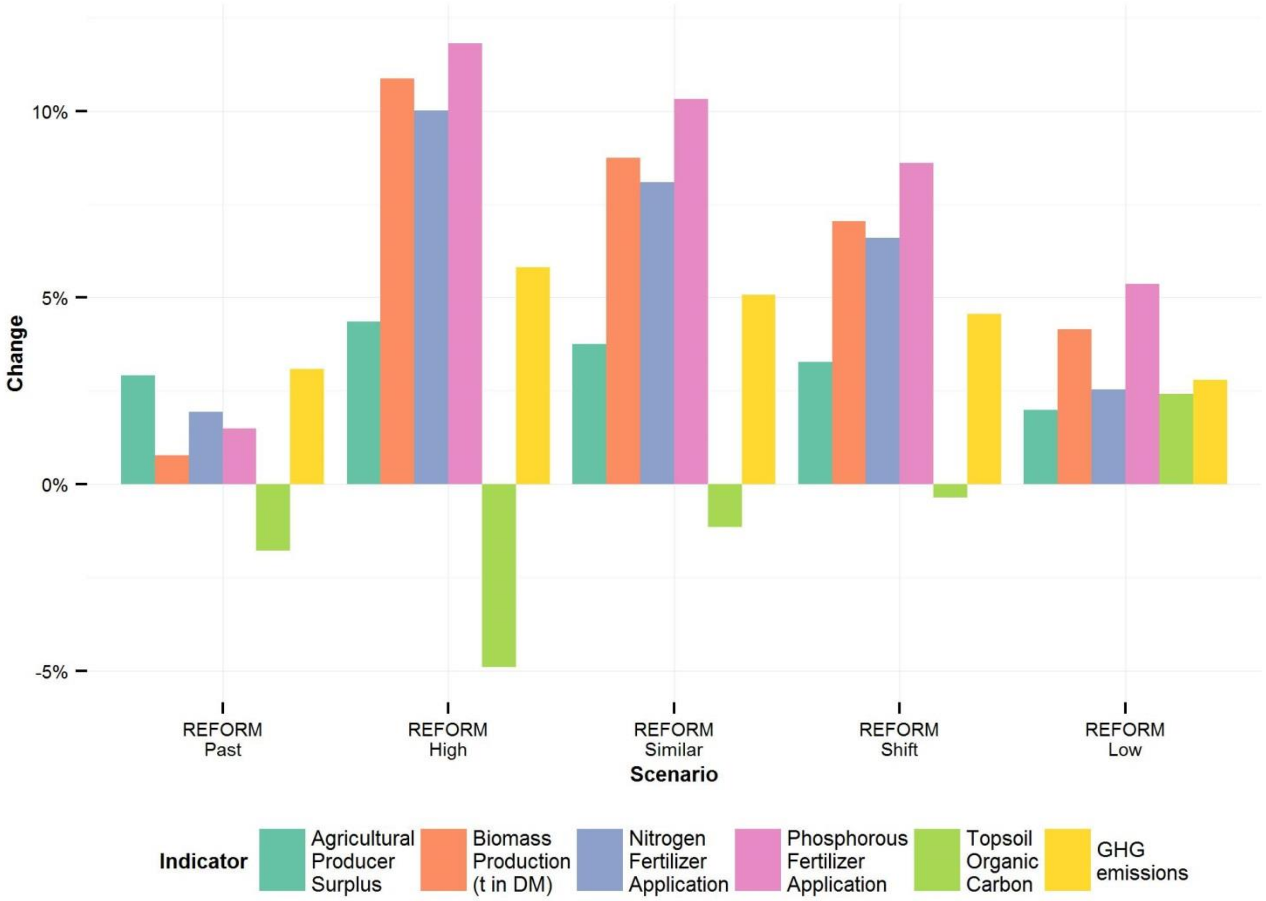

Figure 5: Percentage change in economic and environmental indicators at national level compared to the BASELINE.

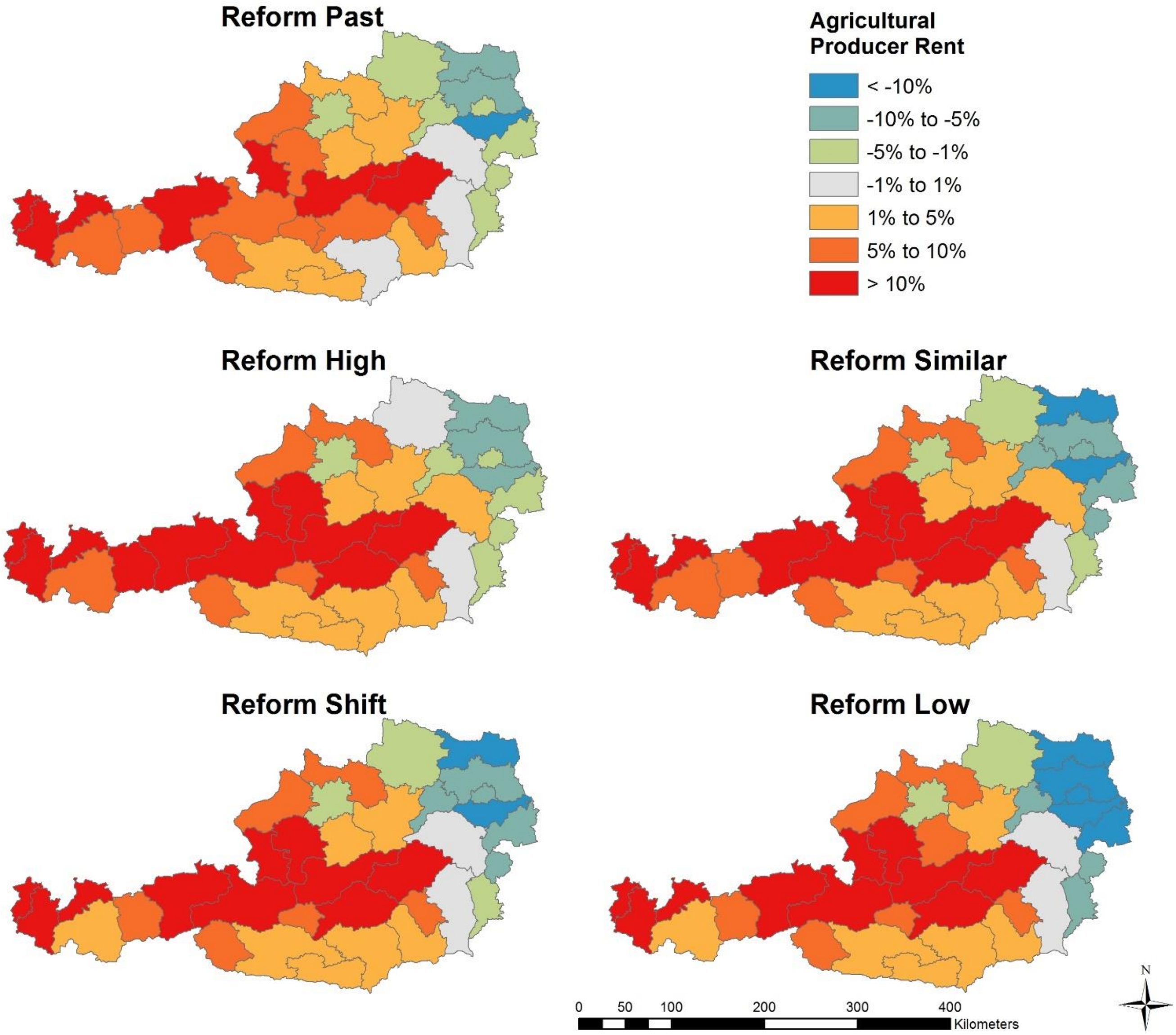

Figure 6: Changes in agricultural producer rent at NUTS3 level due to policy changes (REFORM-Past) as well as policy and climate changes (REFORM-High/Similar/Shift/Low).

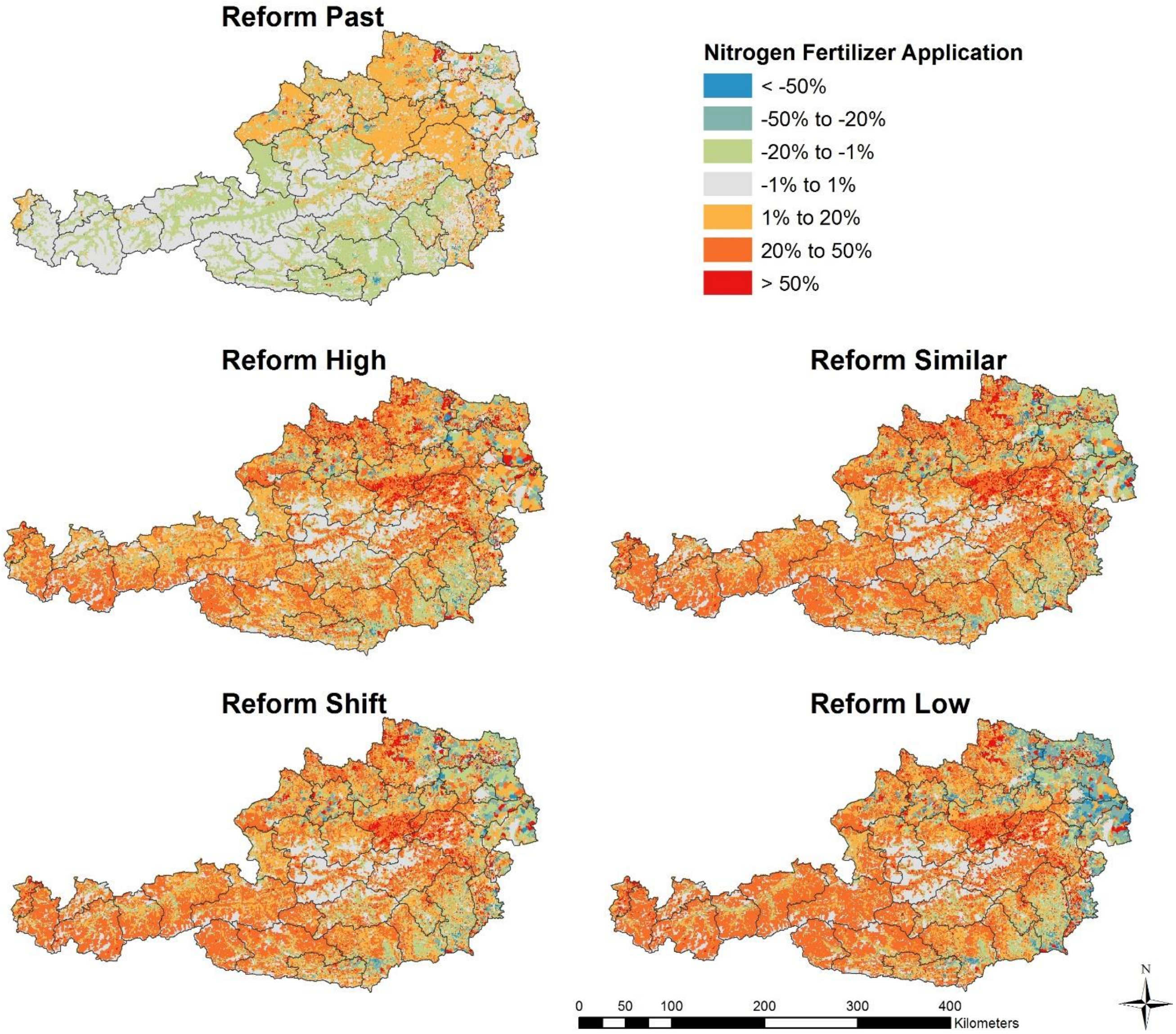

Figure 7: Changes in nitrogen fertilizer application according to PASMA$_{[grid]}$ *results at 1km level due to policy changes (REFORM-Past) as well as policy and climate changes (REFORM-High/Similar/Shift/Low).*