Evaluation of Land Use Based Greenhouse Gas Mitigation Measures in Germany

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Abstract

   Agricultural production contributes 11% to the total German greenhouse gas (GHG) emissions. We evaluate the efficiency of three different land use based GHG mitigation measures: production of feedstocks for biomethane production, short rotation coppices and peatland restoration. We evaluate these measures with respect to cost efficiency (GHG mitigation costs), mitigation potential and impact on agricultural production. We use the regional supply model RAUMIS to investigate the different mitigation measures at the sector and regional level. We extended the modeling framework of RAUMIS to integrate the effects of leakage and indirect land use change. Compared to the production and use of feedstock for bio-energies, peatland restoration is the most cost efficient measure and has the least impact on German agricultural production.

1 Introduction

1.1 *Mitigation strategies in agricultural production*

   In Germany, agricultural production contributes to greenhouse gas (GHG) emissions in various ways. The most important sources are, in decreasing order of importance, drainage of organic soils (CO_2), fertilization (N_2O), enteric fermentation (CH_4), manure management (N_2O, CH_4), and conversion of grassland (CO_2). According to the National Inventory Report (NIR) these emissions account for about 105 Mio. t $CO_{2\text{-eq.}}$ or 11 % of the total German emissions. Different agricultural GHG mitigation alternatives are expected to reduce the GHG emissions and could support the political target to reduce GHG emissions by at least 80% until 2050 (Osterburg et al., 2013).

   GHG mitigation measures in agricultural production are diverse and differ significantly in their abatement effects and their impact on agricultural production programs. Smith et al. (2008) identify three options for how agriculture and land use in general can contribute to reduced GHG emissions. These are (1) the provision of renewable energy, (2) the exploitation of carbon sinks in the soil and vegetation and (3) the reduction of GHG-emissions during the agricultural production process. These three options are either mainly efficiency based (3), land use based (1) or can incorporate both aspects (2). Efficiency based approaches intend to produce the same mix of commodities but with lower emissions per unit. Classical examples of such approaches are, e.g., improved fertilizer spreading technologies, improved feeding strategies or the coverage of manure lagoons. With land used based approaches one produces a different set of commodities. This could be the increased production of bio-combustibles to replace fossil carbon sources, or the cessation of agricultural production to preserve and / or activate carbon sinks (restoration of peatland). In contrast to efficiency based approaches, land use based approaches inevitably compete with agricultural food production for the given land resources. The resulting deficits in food supply for the domestic (and for the export demand) are substituted by imports from other regions (leakage effect). The shift in regional production patterns can even lead to indirect land use changes (iLUC) if the conversion of other land uses into an agricultural use is economically superior to an intensification of production. These effects have to be considered in order to fairly evaluate area based mitigation approaches. Furthermore, the application of mitigation measures and their impact on production are regionally specific and thus regionally very heterogeneous.

1.2   *State of the art*

One can distinguish two broad strains in the literature on the efficiency and effectiveness GHG mitigation in agriculture. The first are "top-down" approaches (e.g., Popp et al., 2011; DeCara and Jayet, 2011). These approaches typically cover a wide range of sub-sectors, technologies and regions. Technologies are normally depicted in a very stylized manner. The representation of technology and innovation is often based on the statistical analysis of observed data on a very aggregated level. A major asset of these models is that they explicitly take into account interactions between different sub-sectors, technologies, or regions that are mediated by market mechanisms. Implicitly they are also able to depict the effect of soft adaptation barriers for mature technologies, however the implementation of technologies not covered by the historical data is a significant challenge. The second strain is comprised of the so-called "bottom-up" approaches (e.g., Moran et al., 2011, Beach et al., 2008). They restrict themselves to a very few technologies and site conditions which are analyzed in detail. Here, the representation of technology and innovation is normally based on detailed information from scientific experiments or case studies. Therefore, the mechanisms inducing the designated changes are fairly transparent. However, these models can not cover indirect effects, e.g., higher efficiency leads to lower production costs and therefore prices inducing an additional demand which partly offsets the mitigation effect achieved at first. Some models have aspects of both strains (e.g., FASOM, CAPRI, RAUMIS). Top down studies on the efficiency and effectiveness GHG mitigation approaches for the agricultural sector are normally limited to non-CO_2-GHG (see, e.g., review in Vermont and De Cara, 2010) or the potential of bioenergy (e.g., Gelfand et. al., 2013) and the emissions from the agricultural use of organic soils are not depicted (Smith, 2012).

Various studies assess the stand-alone potential, costs and co-benefits of different mitigation strategies for Germany using a bottom up approach (e.g., Rösemann et al., 2013; Haenel et al., 2012; Flessa et al., 2012; Osterburg et al., 2009). Furthermore top-down studies analyze the feasibility to reduce non-CO_2-GHG in the agricultural sector at national level (e.g., Osterburg et al., 2013), selected federal states (Neuenfeldt and Schäfer, 2008) or particular mitigation strategies (e.g., Röder and Osterburg, 2010; Henseler and Dechow, 2014).

1.3   Objective of the study

The study at hand presents the first Germany-wide simulation and analysis of three different alternative land used based mitigation measures and their combination. The assessment considers the leakage effects, iLUC, the regional heterogeniety and their impact on GHG balance and on agricultural production in order to provide a more concise evaluation. The modelled mitigation approaches aim at a GHG emission reduction of Germany's agriculture by 20% and imply: the production and energetic use of energy maize, short rotation coppice (SRC) and the restoration of agriculturally used organic soils (i.e., histosols including mainly bogs and fens). This reduction is equivalent to the one due induced by the German renewable energy targets (BMU, 2010). The goal is to assess the efficiency of different land use based mitigation options.

The impacts were analyzed at the sectoral and regional levels and compared with a counterfactual scenario assuming no bio-energy policies. For the scenario simulation, the regional agricultural supply model RAUMIS was extended by additional activities and by a GHG accounting balance which considers leakage and iLUC effects. The following chapter presents the methodological framework, Chapter 3 presents the scenario assumptions. Chapter 4 describes the results at sector and regional level, which are discussed in Chapter 5, followed by the conclusions in Chapter   6.

2   Method: extension of the model RAUMIS

2.1   The General Model

We use the regional model RAUMIS, which is a Regional Agricultural and Environmental Information System designed for policy impact analysis of German agricultural policy and for application in research projects. RAUMIS observes the consistency framework of agricultural statistics. It represents regionally-differentiated agricultural land use, production and income, and is applied for simulations of future projections and scenario analysis (Weingarten, 1995; Henrichsmeyer et al., 1996).

As an agricultural supply model, RAUMIS is a process analytical optimisation model and the calibration is based on a positive mathematical programming (PMP) approach (Howitt, 1995). RAUMIS simultaneously optimizes the agricultural production for 326 spatial units (NUTS 3 counties). The regional agricultural production decisions are driven by the maximisation of the agricultural income, which is the objective value of a system of non-linear production functions. RAUMIS differentiates more than 50 products from 40 production activities. Regional production statistics are the basis for the computation of the extension of production activities and yields in the counties. Regional data of production structures and input factors, such as nitrogen input are modeled in a process analytical formulation. Thus, RAUMIS can simulate land use, agricultural production and nitrogen application (Henseler and Dechow, 2014).

Every second year a baseline scenario is calculated as a reference for further policy impact studies (Offermann et al, 2011). This baseline projects the development of the German agricultural sector for the next ten years. The results of the baseline are discussed with and approved by regional and national agricultural experts.

In order to address the research question we extended RAUMIS with respect to three aspects. The first is the inclusion of energy crops. We newly depict short rotation. Gömann et al. (2007) implemented the production of feedstock for biogas production by the production activity of energy maize. The production of feedstocks for bioethanol and biodiesel production is not explicitly modeled. For rape seed and cereals we do not define different production activities with respect to the latter use of the feedstock for different reasons. The respective feedstocks are globally traded. Furthermore, the later use of the feedstock as fuel on the one hand, and food or feed on the other, does at best marginally impact the respective production activity in the field. Secondly, we differentiate the use mineral and organic soils within one county. Thirdly, we extended the GHG accounting module.

2.2   Production of feedstock from short rotation coppice

The energetic usage of feedstock from short rotation coppice was implemented newly into RAUMIS as production activities differentiated as short rotation coppice on arable land and grassland. Due to the lack of representative regional data, a location model was newly developed which estimates the area potential, yield and costs functions for each county.

2.3   Restoration of agriculturally used peatland

To represent the restoration of agriculturally used peatland, its regional extension was derived for the NUTS3 counties based on geological maps (BGR, 2003) and remote sensing land use information (BKG, 2008). The land use was differentiated into arable land and into intensive and

extensive grassland (for a detailed description of the method see Röder and Osterburg, 2012). Due to the lack of data the implementation differences in relative activity levels could not be discriminated between organic and mineral soils within one county. The restoration of organic soils itself was implemented as an additional land use activity which reduces the pool of regionally available arable and grassland and thus represents the abandonment of the agricultural production on organic soils.

2.4   Balancing the GHG emissions

GHG accounting in RAUMIS consisted of two models accounting the regional GHG emissions from agricultural crop and animal production: RAUMIS-MODE (for N_2O emissions from crop production) and RAUMIS-GAS-EM (for CH_4 and N_2O emissions from livestock) (Henseler and Dechow, 2014; Henseler et al., 2013). We added two sub-modules: the first adds the emissions saving induced by the use of domestically produced bioenergy crops. The savings are based on the efficiency of typical conversion chains. The second sub-module accounts for the leakage effects.

Table 1 presents the emission credits for the energetic usage of biofuels, biogas and wood chips. The data is based on various sources and applied to the corresponding production activities for cereals, rape seed and short rotation coppice. The CO_2 emission credits resulting from restoration of organic soils (i.e., the abandoning of production and reducing agricultural carbon source) are represented by regional emission factors for N_2O and CO_2 emissions differentiated into arable land, intensive and extensive grassland on organic soils (Drösler et al., 2013). The calculation of the regional factors takes soil type, land use and regional stocking densities into account.

Table 1: Emission credits for energetic usage of bioenergy (without fertilization) and ranges of regional emission factors for agricultural production on organic soils.

	GHG emission credit	Range or regional emission factors
	Ton CO_2 per ton product	Ton CO_2 per ha
Green maize for biomethane	0.256	
Cereals for bioethanol	0.251	
Rapeseed for biodiesel	0.91	
SCR for wood chips	0.963	
Arable land on organic soil		20.6 to 30.5
Intensive grassland on organic soil		17.1 to 28.3
Extensive grassland on organic soil		7.4 to 23.5

Sources: Drösler et al. (2013), WBA (2007), (UBA, 2012)

The analyzed land-use based mitigation option will frequently lead to a reduced production of classical agricultural commodities (food, feed, and fibre). We assume that the lower German production will be compensated by an increased production elsewhere in the world. We account for leakage effects by weighting the production difference by product specific emission factors according to Osterburg et al. (2013) or alternatively derived from Pérez Domínguez et al. (2012). The estimate of the emissions due to indirect land use change (iLUC) is based on Fritsche et al. (2010).

3   Scenarios

The simulation of four scenarios assumed the application of different mitigation options, which

were analyzed, compared and evaluated.

In the first step, we constructed a counterfactual **scenario** without bioenergy policy (**woBEP**) assuming no bioenergy policies. Lacking competition for production factors (land) between energy crops and food crops result in low agricultural prices and a low level of agricultural imports. As a conterfactual scenario it serves as reference to analyze the impacts of the policies simulated by comparing with the policy scenarios (Blanco et al., 2009). In scenarios with simulated mitigation measures, the differences in agricultural production to the scenario **woBEP** are defined as the leaked production.

In the second step, we estimate the amount of emissions that could be saved given a full implementation of the national renewable energy action plan (NREAP). The NREAP scenario leads to roughly 20% lower emissions compared to the counterfactual (Bues et al.; in press). The NREAP scenario strongly supports the production of bioethanol wheat and coarse grains and bio diesel from rapeseed. In addition the production of biomethane is supported.

In the third step we analyze the costs and land use implications of the different mitigation options. We introduce a subsidy honoring the reduction of GHG emissions. This emission subsidy is modified as long the respective mitigation option achieves an emission reduction equivalent to the one in NREAP. The analyzed mitigation options are the cultivation of maize for the production of biomethane, cultivation of short rotation coppices and the restoration of peatlands. We did not analyze the production of biofuels as they accounted for only 10% emission savings in NREAP but demanded nearly 40% of the area cultivated with energy crops.

The "market" feedstock price for energy maize is determined by the electricity trade price of 4,75 ct / kWh (roughly the average price for electricity at the European Electricity Exchange for 2012). Because of low market prices for electricity the feedstock price for energy maize would be -16 EUR per ton. Based on current market prices (C.A.R.M.E.N., 2013) we set price of 126 EUR per ton of woodchip produced from short rotation coppice.

In **scenario Emaize** a subsidy of 115 EUR per ton CO_{2eq} is needed to achieve the intended GHG reduction. In scenario **SRC** short rotation coppice can be established on arable land and grassland outside protected areas. 500 EUR per ton CO_{2eq} are needed to achieve the intended GHG reduction. In scenario **Peat** the abandonment of agricultural production on organic soils is supported by payments of 20 EUR per ton CO_{2eq}. In scenario **All** a subsidy of 18 EUR per ton CO_{2eq} is sufficient.

Table 2 provides an overview on the scenario assumptions.

Table 2: Scenario assumptions

Assumption	woBEP	Emaize	SRC	Peat	All
Additional imports compared to woBEP required?	no	yes	yes	yes	yes
GHG-mitigation policy	No bioenergy policy/counterfactual,	energy maize with market electricity price	Short rotation coppices	Abandonment of agricultural production on organic soils	combination policies of scenarios Emaize, SRC and Peat
Support price / Mitigation price per ton $CO_{2\,eq}$ to reach the 20% reduction target.	none	115EUR/ton	500EUR/ton	20EUR/ton	18EUR/ton

4   Results

The simulated scenarios result in changes in GHG emissions from agriculture and in agricultural production. On the sectoral level the analysis indicates the total impact of the simulated policies,

while the regional analysis illustrates regional heterogeneous reactions in agricultural production.

4.1 Sector analysis

Table 3 presents the sector results for emissions and agricultural production in the simulated scenarios. In the counterfactual scenario **woBEP** the absence of energy policy with support for bioenergy production or for GHG mitigation results in agricultural GHG emissions of 80 Mio. t CO_{2eq}.[1] Because little agricultural area is used for the production of energy crops, the cereals production area is with 6.5 Mio. ha larger than in the other scenarios, though the low agricultural prices result in relatively large areas of set aside.

Due to scenario definition, the simulated alternative mitigation measures in the scenarios **Emaize, Peat, All** reach a reduction of GHG emissions of at last 20% considering leakage effects and iLUC.

In the scenario **SRC** the support of SRC by 500EUR per ton mitigated CO_{2eq} only allows a reduction of 14% because the extension of production area for short rotation coppice is limited by the available marginal arable land (1.2 Mio ha) and grassland (1.3 Mio ha).

In the scenarios in which restoration of organic soils (i.e., abandonment of agricultural production on organic soils) is feasible (**Peat** and **All**), the support payments per ton mitigated CO_{2eq} are comparatively low.

The magnitude of the leakage effect was largely independent of the used data (German: Osterburg et al., 2013; Likely countries of origin: Pérez Domínguez et al., 2012).

4.2 Regional analysis

Map 1 to 6 present selected regional results for the agricultural production in the simulated scenarios. In scenario **woBEP** the low agricultural prices result in set aside areas of regionally different sizes. In regions with marginal arable land the share of set aside area reaches 12% of agriculturally used area (UAA) (e.g., in eastern Germany). In regions with intensive livestock production less area is set-aside (e.g., in the Münsterland or in the Allgäu, cf. Map 1).

In the scenario **Emaize** high shares of energy maize are found in regions with high arable yields (e.g. in central Germany, corn belt) (cf. Map 2).

In scenario **SRC** the area with short rotation coppice increases two different regions. The first region is characterized by a high share of marginal arable land (e.g., in Eastern Germany, Brandenburg, Saxony-Anhalt). Here short rotation coppice competes with low input cash crops (e.g., rye and meslin).

The second region is southern Germany where short rotation coppice is highly competitive due to its high yield potential caused by high summer temperatures and high levels of precipitation. However, short rotation coppice area remains small in regions with high arable yields (e.g., the corn belt) or intensive livestock production and cooler and drier summers (e.g., in Northern Germany), cf. Map 3.

In the scenario **Peat** large areas of agricultural production are abandoned on organic soils, particularly in Northern and Eastern Germany. In regions with high intensive dairy farming the fodder area on organic soils are retained (e.g., in the north of Lower Saxony, in Schleswig-Holstein and in Bavaria, cf. Map 4). In scenario **All** the dominating measures are short rotation coppice and

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[1] The simulated agricultural GHG emission in the counterfactual are smaller than accounted by the national inventory (UBA, 2013), which can be explained by differences in: emission factors, extensions of organic soils, conversion of grassland, application of $CaCO_3$ and in the assumed future development of the cattle stock.

restoration of organic soils, the regional land distribution of which is similar to the scenarios *SRC* and *Peat* in north-eastern, eastern and southern Germany.

5   Discussion

Compared to the counterfactual scenario the simulated mitigation measures result in a GHG reduction of about 20%.

In the scenarios *Emaize* and *SRC* the support payments for the production of alternative renewable energies from biogas (energy maize) or short rotation coppice range from 115 to 500 EUR/t CO_{2eq}. The lowest costs are indicated by scenarios assuming the restoration of organic soils with 20 EUR/t CO_{2eq}. However, the marginal costs for the restoration do not include the costs for planning, water engineering the transition period, and for the impacts on adjacent land use systems (e.g., settlements, forests).

Furthermore, the production of bioenergy and the restoration significantly reduces the area available for food production and increases the competition for land and will therefore induce higher agricultural prices.

The regional simulation results in the scenario *Emaize* indicate large energy maize areas in the corn belt, where soils fertility result in high crop yields. Actually observed trends do not confirm this simulated development. This difference might result from aspects which are not considered in RAUMIS modeling approach: high competition between food crops and energy maize and the long term nature of changing the production program from a very flexible and highly profitable cash crop production (e.g., wheat, sugar beet) toa more profitable energy maize production. The latter is less flexible because the energy maize processing (e.g. fermentation for biogas production) requires the long term establishment and expansion of a special infrastructure. However, the energy maize production in less productive regions or in combination with livestock production might result in a lower production of energy maize than simulated.

In terms of cost efficiency the scenario **All** results with 18EUR/t CO2eq in the smallest mitigation costs. In **All** mainly the two strategies **SCR** and **Peat** are realized, since engergy maize production starts to be profitable only with subsidies of 115 EUR/t CO_{2eq}. The measure **Peat** is ranked   closely   second,   followed   by   the   measures   in   **Emaize**   and   **SRC**.

Table 3: Costs and simulated emissions from crop and livestock production.

|		woBEP	Emaize		SRC		Peat		All	
		absolute	absolute	Diff. to woBEP	absolute	Diff. to woBEP	absolute	Diff. to woBEP	absolute	Diff. to woBEP
Costs	EUR/t CO_2 eq	---	115.0		500.0		20.0		18.0	
Emissions										
Crop production	t CO_2 eq	29.9	30.6	0.7	27.4	-2.5	29.6	-0.3	29.9	0.0
Livestock	t CO_2 eq	25.6	25.6	0.0	24.4	-1.2	25.3	-0.3	24.8	-0.8
Organic soils	t CO_2 eq	25.1	25.1	0.0	25.1	0.0	5.7	-19.4	9.6	-15.5
Energy crops	t CO_2 eq	-0.9	-20.5	-19.6	-15.7	-14.8	-0.8	0.1	-5.4	-4.5
Energy maize	t CO_2 eq	0.0	-19.7	-19.7	0.0	0.0	0.0	0.0	0.0	0.0
Short rotation coppice	t CO_2 eq	0.0	0.0	0.0	-14.8	-14.8	0.0	0.0	-4.6	-4.6
Other energy crops	t CO_2 eq	-0.9	-0.9	0.0	-0.9	0.0	-0.8	0.1	-0.8	0.1
Sum without iLUC	*t CO_2 eq*	*80.3*	*62.0*	*-18.3*	*64.0*	*-16.3*	*60.8*	*-19.5*	*60.9*	*-19.4*
Compared to woBEP	%	100.0	77.0	-23.0	80.0	-20.0	76.0	-24.0	76.0	-24.0
iLUC	t CO_2 eq	1.3	3.5	2.2	6.1	4.8	2.2	0.9	4.0	2.7
Sum incl. iLUC	*t CO_2 eq*	*81.5*	*65.5*	*-16.0*	*70.2*	*-11.3*	*63.0*	*-18.5*	*64.9*	*-16.6*
Compared to woBEP	%	100.0	80.0	-20.0	86.0	-14.0	77.0	-23.0	80.0	-20.0
Crop production										
Cereals	Mio. ha	6.5	5.1	-1.4	5.8	-0.7	6.3	-0.2	6.1	-0.4
Rapeseed	Mio. ha	1.3	1.2	0.0	1.3	0.0	1.2	-0.1	1.2	-0.1
Silage maize	Mio. ha	0.9	2.3	1.4	0.9	0.0	0.9	0.0	0.9	-0.1
Energy maize	Mio. ha	0.0	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Short rotation coppice on arable land	Mio. ha	0.0	0.0	0.0	1.2	1.2	0.0	0.0	0.3	0.3
Arable land (excl. fallow)	Mio. ha	11.2	11.1	-0.1	11.1	-0.1	11.5	0.3	11.3	0.2
Short rotation coppice on grassland	Mio. ha	0.0	0.0	0.0	1.3	1.3	0.0	0.0	0.2	0.2
Grassland (excl. allow)	Mio. ha	5.1	5.1	0.0	3.9	-1.2	4.8	-0.3	4.7	-0.4
Fallow	Mio. ha	0.4	0.4	0.0	0.0	-0.4	1.0	0.7	0.7	0.4
Energy crops	Mio. ha	0.2	1.6	1.4	2.7	2.4	0.2	0.0	0.7	0.5
Fodder area	Mio. ha	6.7	6.7	0.0	5.6	-1.1	6.4	-0.3	6.3	-0.5
Virtual land trade	Mio. ha	0.4	1.0	0.6	1.7	1.4	0.6	0.3	1.1	0.8
Livestock										
Dairy Cows	Mio. LU	3.9	3.9	0.0	3.6	-0.2	3.8	0.0	3.8	-0.1
Other cattle	Mio. LU	4.3	4.4	0.0	4.2	-0.2	4.3	-0.1	4.2	-0.1
Other animals	Mio. LU	4.5	4.5	0.0	4.5	0.0	4.5	0.0	4.3	-0.2

Source: Own calculations
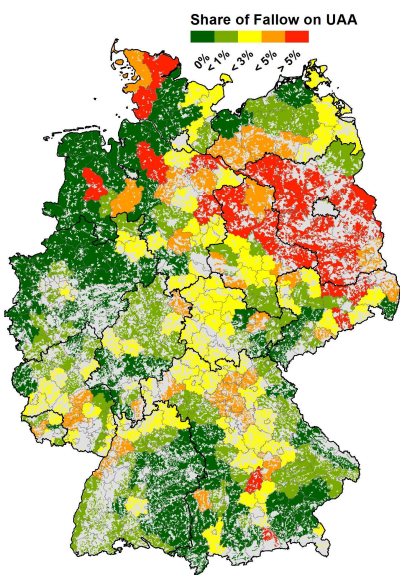
Map 1: Set aside in scenario woBEP
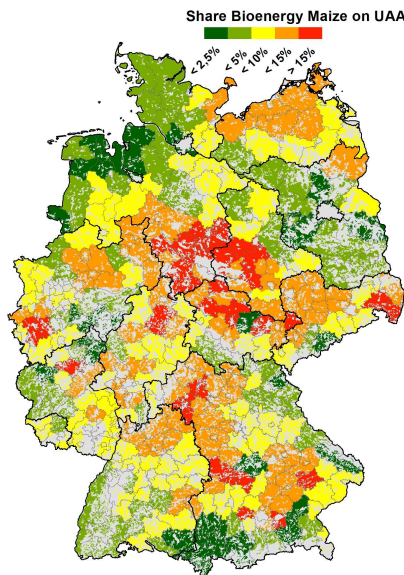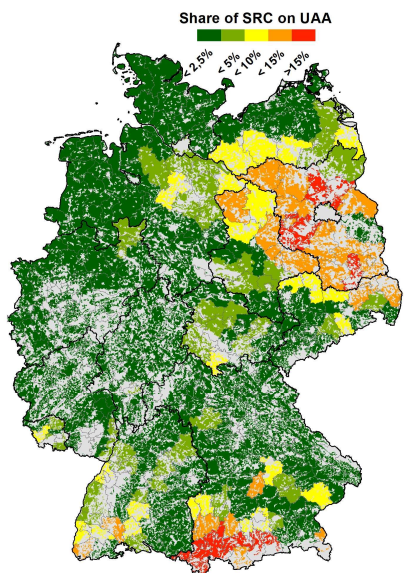

Map 2: Energy maize area in scenario Emaize
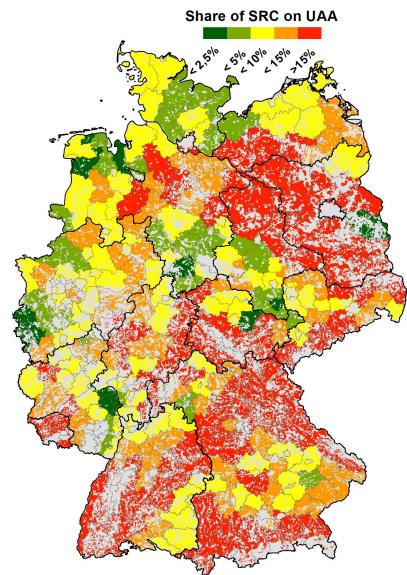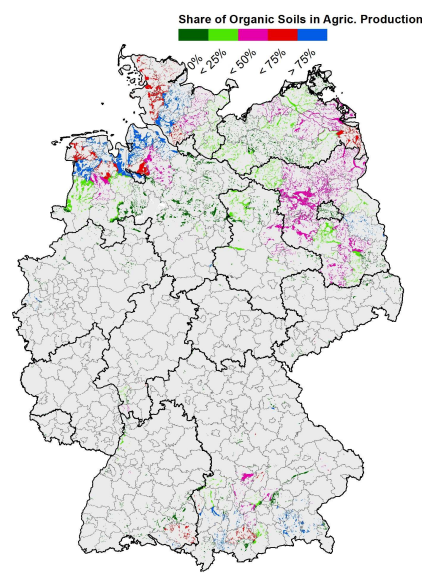

Map 3: SRC area in scenario SRC
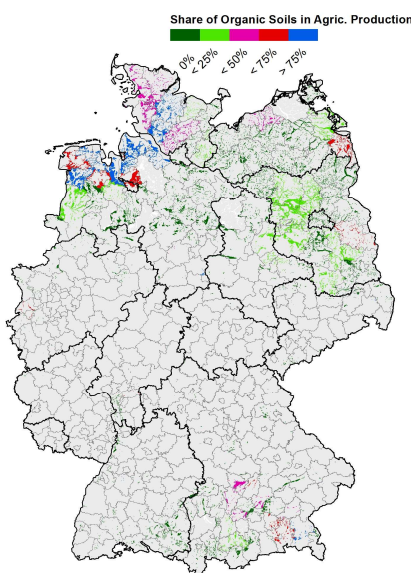
Map 4: Organic soils under production in scenario Peat

Map 5: SRC area in scenario All

Map 4: Organic soils under production in scenario All

Source: Own calculation

6   Conclusions

We assessed the impact of different land based mitigation measures for German agriculture on the GHG balance and agricultural production with the help of four different scenarios. We used the model RAUMIS as an analytical framework. We extended its GHG balance by considering leakage and iLUC effects, the restoration of agriculturally used organic soils and the production activity of SRC. The extension of RAUMIS allowed for a comparison of the impacts of the mitigation measures at sector and at regional level.

Compared to a counterfactual scenario, without any policy intervention, all investigated measures reduced the GHG emissions significantly. As standalone option both the production of

energy maize and the restoration of agriculturally used organic soils could achieve the given target of a 20% emission saving. The maximum area of short rotation coppices is limited by the assumptions regarding the extent of suitable and available land, and thus achieves a GHG emission of only 14%. The restoration of agriculturally used organic soils achieves the reduction target with by far the lowest marginal costs of 20 EUR per ton mitigated ton CO_{2eq}. However, transaction and engineering costs are not considered. As expected the combination of all three measures in **All** is the most cost efficient option to reach the GHG emission target. However, the cost saving of 2 EUR per ton mitigated ton CO_{2eq} compared to the scenario **Peat** is fairly small. The emission reduction in scenario **All** is achieved by the restoration of agriculturally used organic soils (77%) and the cultivation of short rotation coppices. The results show that the most intensively option, i.e. the production of biogas based on maize, is by far the most expensive mitigation option. Therefore, we argue to phase out the promotion of bioenergy production based on maize and to shift the focus to the more economic options.

At regional level the impacts of the mitigation measures on agricultural production are very different. While the largest extension of energy maize production is simulated in high yield arable regions, short rotation coppice production is concentrated either on marginal soils or regions with high summer temperature and summer precipitation. The restoration of organic soils appears in all regions with agricultural production of organic soils, but less in regions with intensive livestock production.

The scenario analysis within the developed analytical framework provides results which can be of use for policy support and the evaluation of mitigation measures. The given framework for the analysis of German agricultural policies was improved with respect to two issues. First, a wide range of different land-use based mitigation options have been included in the model. Second, the first assessment of leakage-effects of given policies is possible without the need to run global trade models (e. g., MAGNET). In the future two aspects will be adapted. First, the modeling of energy maize needs to be revised and second the restoration of organic soils should include an estimate of transaction and engineering costs.

7 Literature

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