A Grassland strategy for farming systems in Europe to mitigate GHG emissions - An integrated spatially differentiated modelling approach

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Abstract

This paper assesses the impact of an EU-wide policy to expand grassland area and increase carbon sequestration in soils. The paper uses the economic Common Agricultural Policy Regionalized Impact (CAPRI) model which represents the EU Agriculture by 2,450 mathematical programming farm type models in combination with the biogeochemistry model CENTURY which determines the carbon sequestration at a high resolution level. Both models are linked at the NUTS3 level using the location information in the Farm Accounting Data Network. We simulated a grassland premium such that farmers increase grassland by 5% cost efficiently, whereas we assumed that farmers with lower costs can contribute more. Our findings are that the GHG mitigation potential and costs depend on carbon sequestration rates, the land market and the induced land use changes, and the regional agricultural production structure. The overall net effect in Europe simulated with the model is a reduction of 4.3 Mio t CO2e (equivalents) when converting 2.9 Mio ha into grassland. A premium was calculated so that farmers increase grassland voluntary. It amounts on average to 238 EUR/ha, summing up to a total cost of 417 Mio EUR. The net abatement costs are based on the premium payments and account on average 97 EUR/t CO2e. Substantial carbon sequestration (28% of the total sequestration) can be achieved already with 50 EUR/t CO2e. The carbon sequestration would be most effective in regions in France, Italy and Spain, the Netherlands and Germany. Larger farms and farm types specialized in cereals and protein crops, mixed field cropping, granivores and the mixed crops-livestock farming have the highest potential to relatively low costs.

1 Introduction

The agricultural sector is both a source and a sink of greenhouse gases (GHG). In this context, agricultural soils play a major role as they contain a large stock of terrestrial carbon in the form of soil organic carbon (SOC). SOC can be enhanced by further sequestration or depleted via carbon dioxide (CO_2) emissions, depending on factors such as vegetation, climatic conditions and farming practice. In the roadmap for moving to a low-carbon economy (EC, 2011) the EU envisages the reduction of net CO_2 equivalent emission from agricultural soils and forest through targeted measures. A key goal of the strategy is to enhance SOC levels across the EU by 2020. Besides restoring of wetlands and peat lands, tillage farming practices, reduction of erosion and re- or afforestation, the EU has introduced a ‘greening’ element into the Common Agricultural Policy (CAP) post-2013 to promote, amongst others, the maintenance of permanent grassland. This avoids CO_2 releases from soils and maintains carbon in grassland. However, because in most Member States (MS) the demand for urban areas cause an area decline in agriculture also grassland will further decline. This is already an observed trend between 1990 and 2012 where arable land and permanent crops decreased by 15% and grassland by 19% in the EU (FAOSTAT, 2014). Compared to other agricultural vegetation, grassland ecosystems represent a significant below ground terrestrial carbon pool and can additionally convert atmospheric carbon in biomass above-ground. That a conversion of arable land into grasslands can enhance carbon sequestration has been proven by many researchers. Conant et al. (2001) reviewed more than 100 empirical studies in this context worldwide. Vleeshouwers and Verhagen (2002) quantified the effects using the bio-physical model CESAR[1] in Europe and concluded that the carbon sequestration potential of increasing grassland area is large. Ogle et al. (2004) and Freibauer et al. (2004) present an overview of studies that examine the effect of grassland conversion on SOC. Even although the process of converting arable into grassland and its resulting carbon sequestration is well understood and quantified; the economic effects induced by enhancing grassland, such as changes in prices, production, trade and indirect emissions are not assessed in the literature and consequently it is difficult to conclude on abatement costs. In the literature, it is furthermore pointed to the need for finding better estimates to identify the area in Europe which is most feasible to carry out specific carbon sequestration measures with respect to regional differences in efficacy (Freibauer et al., 2004).

In this paper we develop a modelling approach to assess economically the consequences of a 5% grassland increase in the EU27[2] to find out the amount of carbon that could be sequestered, the abatement costs and the economic implications on the farming system in Europe. The partial equilibrium model CAPRI[3] and its farm type supply module (Gocht and Britz, 2011), which accounts for the high variability in agriculture, is used to assess the economic effects. We allow that different farm types (different farm specialisation and size) can adjust differently to reach the 5% target at the NUTS2 level[4] and that the adjustment is cost efficient, hence, depending on the production costs of each simulated farm. The carbon sequestration and abatement costs for the farm types are calculated using carbon sequestration rates from the biogeochemistry carbon sequestration model CENTURY. These rates depend on soil qualities and climatic conditions and are spatially distributed at a high resolution level in Europe. As the location of the farm supply models in CAPRI is not directly known[5], we approximate the location using information from the Farm Accountancy data Network (FADN) on the spatial distribution of farm types to map the sequestration rates from CENTURY at the highest possible resolution.

The paper contributes to the existing literature in two ways: (i) This is the first application to our knowledge in which spatial explicit carbon sequestration rates are used in an economic farm type model, not linked at the regional aggregate, but spatially mapped based on an approximation of the location of the farm type using FADN. As the environmental and economic effects depend strongly on the farming systems the implemented approach consequently yields in less biased GHG abatement costs estimates[6] compared to a regional approach. (ii) The approach also quantifies the complete GHG balance in agriculture, by taking not only the carbon sequestration as sink into account but also other GHG emissions (CH4, N2O) induced by herd size and land use changes, resulting from the grassland increase.

The paper is structured as follows: First, we describe the CAPRI economic model approach and how we derived the location of the farm types using FADN to map spatially the SOC rates (obtained from the biogeochemistry model CENTURY)[7]. To better understand the spatially explicit mapping we compare it to a standard mapping at a lower resolution. Afterwards, we describe the scenario and present the results. We begin with the analysis of land use changes and analyse the changes in trade, commodity prices and supply. We show the findings on carbon sequestration and discuss the impact

[1] Carbon Emission and Sequestration by Agricultural land use
[2] Croatia is not yet incorporated in the CAPRI farm model
[3] Common Agricultural Policy Regionalized Impact
[4] Currently we have 270 NUTS2 regions in the EU-27. The 5% target needs to be realized by all farms in a NUTS2 region. We have chosen this resolution as many agri-environmental programs and greening measure for maintaining grassland of the CAP are evaluated at this regional level.
[5] above the NUTS2 resolution
[6] An evaluation at the regional level, instead of farm type level, would result in higher aggregation errors and therefore can hide effects of interest and bias the real CO2 abatement costs.
[7] The interested reader can refer to Lugato et al. (2014) for a description of the CENTURY model

on emissions and we finalize the results section presenting the abatement costs of CO_2 emissions. We conclude by summarizing the key results and point at further research directions.

2 The economic model

To analyse land use, price and production effects we use the Common Agricultural Policy Regionalized Impact (CAPRI) model and its farm type supply module. The model was recently applied to assess the CAP for direct payment harmonisation (Gocht et al., 2013), effect of Rural Development Programs (Schroeder et al., 2014) or the impact of the CAP greening measures (Zawaliñska et al., 2014). The modelling system is a comparative-static partial equilibrium model, which iteratively links the farm type supply modules with the global multi-commodity market module. The 2,450 farm type supply models in CAPRI represent the EU27 (Gocht and Britz, 2011). The farm types mainly aims to capture heterogeneity within a region, in order to reduce aggregation bias in response of the agricultural sector to policy and market signals, with a specific focus on farm management, farm income and environmental impacts. The model is built from the Farm Accountancy Data Network (FADN) and the Farm Structure Survey (FSS) data. It consists of independent non-linear programming models for each farm type, representing, as an aggregate, all activities of all farms falling in a particular type of farming and size class. The model capture the premiums paid under the CAP in high detail. It includes NPK[8] balances and a module with feeding activities covering nutrient requirements of animals. Besides the feed constraint, other model constraints relate to arable land and grassland. Grass, silage and manure are assumed to be non-tradable and receive internal prices based on their substitution value and opportunity costs. The farm types are characterized along two dimensions as depicted in Table 1: (i) by production specialization (type of farming) and (ii) the economic size class of farm represented in terms of European size units (ESU)[9]. We consider 13 production specializations and 3 farm sizes. In total, this leads to 39 possible farm types. However, not all the farm-types in each NUTS2 region can be modelled due to storage restriction, computing time and the feasibility of analysing results. Therefore, we apply a selection approach which maximizes the representation (in terms of UAA and Livestock Units) of all the selected farm-types at the EU27 level including as constraint that the total number of farm-types included in the model is not aver 2,450 (Gocht et al., 2014). The remaining farms (at NUTS2 level), build up the residual farm type, also represented by a mathematical supply model.

Each farm type has its own land supply (Jansson et al., 2013) and thus its own shadow price for the different land uses (agricultural land versus non-agricultural land). The CAPRI model has a GHG emission module (Pérez-Dominguez et al., 2012) which has been used to assess GHG emissions and to analyse environmental options to mitigate greenhouse gas (GHG) emissions mitigation and environmental options in several studies: Leip et al. (2010) and Weiss and Leip (2012) used the data on livestock GHG emissions from CAPRI for analysing the GHG emissions of EU livestock production in form of a life cycle assessment; Leip et al. (2014) assessed the nitrogen footprint of food product on basis of the nitrogen flows in agriculture derived from CAPRI; Shrestha (2013) employed the CAPRI model to identify economic effects of climate changes on the EU agriculture.

[8] Nitrogen, Phosphorous, Potassium
[9] http://www.capri-model.org/

Table 1: The dimension of the farm types in CAPRI

i) Type of farming	ii) Economic size class
Specialist cereals, oilseed and protein crops (FT13)	< 16 ESU[10]
General field cropping + Mixed cropping (FT14_60)	≥ 16 ≤ 100 ESU
Specialist horticulture (FT2)	> 100 ESU
Specialist vineyards (FT31)	
Specialist fruit and citrus fruit (FT32)	
Specialist olives (FT33)	
Various permanent crops combined (FT34)	
Specialist dairying (FT41)	
Specialist cattle + dairying rearing, fattening (FT42_43)	
Sheep, goats and other grazing livestock (FT44)	
Specialist granivores (FT5)	
Mixed livestock holdings (FT7)	
Mixed crops-livestock (FT8)	

2.1 Finding the location of the farm types in CAPRI to calculate SOC sequestration

To calculate the effects on SOC by farm type and to be able to sum up the effects, we need to link the bio-physical SOC rates to the farm types. If we would have the location of the farm types we could link directly the spatial explicit information on SOC rates. But the location is unknown as data confidentiality rules of EUROSTAT restrict the use. To approximate the location of a farm type in a NUTS2 region we use the location information from the EU-wide FADN data base. The database is a representative survey of approximately 80,000 farms across EU27 representing the farm population in the EU. Each farm survey also provides the county (NUTS3) information where the farm is located. We utilize the information in combination with the knowledge about the type of farming (FT) and economic size class size (ESC) to calculate a weighing matrix as given in Table 2 (as example a German region is presented (DE21)[11]). The matrix defines how likely it is that a farm type is located in a certain county. We map the SOC rates from the CENTURY model, presented in the last column, into the farm type models using the likelihood as weights. In Table 2 the first column indicates the regional levels at county level. In the NUTS2 region DE21 we have 16 counties (NUTS3 regions) with FADN records given for the year 2007. The other columns indicate the number of farms (weights) in the county by farm type. We observe that particular dairy farms are located in L and K with a SOC factor 8.9 and 9.3, whereas cereals and protein crop farms are located only in county 9 with a SOC of 10.6. This results in SOC rates per farm type as indicated in the last row of The rates indicate the amount of carbon in tonnes sequestrated over a certain time period and are calculated using the biogeochemistry model CENTURY (Lugato et al., 2014; Parton et al., 1988). The model uses spatial and numerical databases developed at EU level to quantify carbon sequestration in grassland. We have quantified carbon sequestration rates based on a conversion scenario from arable to grassland at a high resolution level for the EU27. To derive the SOC rates the CENTURY a business as usual and a conversion scenario from arable to grassland was calculated. The CENTURY works at a high spatial resolution: the soil climate land use units, which have been aggregated to county level (NUTS3) for the mapping, as explained above. Soil carbon sequestration does not have unlimited potential to offset CO_2 emissions. Long term experiments have shown that increases in soil carbon are larger immediately after arable land was converted to grassland (Smith et al., 1997). To

[10] ESU = Economic Size Unit; Each ESU is equivalent to 1200 EUR gross margin.
[11] Here we only presented the results for the largest size class above 100 SGM.

avoid an overestimation the average of seven years is used in the economic modelling. We calculate the carbon sequestration rates per year from the seven years and convert the carbon in global warming relevant CO2e emissions per year.

Table 2 using the county level SOC rates from the CENTURY model (last column).

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Table 2: Number of farms in a region in Germany to spatially allocate the farm types at count resolution and resulting mapped SOC coefficients

	Type of Farming in FADN								CENTURY
County	FT13	FT14_60	FT2	FT41	FT_42_43	FT50	FT7	FT8	SOC [t C/ha/7yrs]
3				64					8.8
4							12		6.2
5				637		9			8.9
8				127					8.0
9	136	344		91	18	30		70	10.6
A				64	34			23	7.3
C		27							7.6
E		27				10			7.9
F			23						9.7
G				255	69			23	7.5
I					69			45	7.9
J		507		64		9		23	7.8
K				892	34				9.3
L				64					5.5
M				345	69			23	8.7
N				64	34				8.3
CAPRI [t C/ha/7 yrs]	10.6	8.8	9.7	8.7	8.2	9.4	6.2	8.8	

[12] Generally we could also iteratively link both models exchanging the cropping pattern during the simulation. However, as land use changes are not tremendous and the classes in CENTURY are rather aggregated compared to the economic model this was not applied.

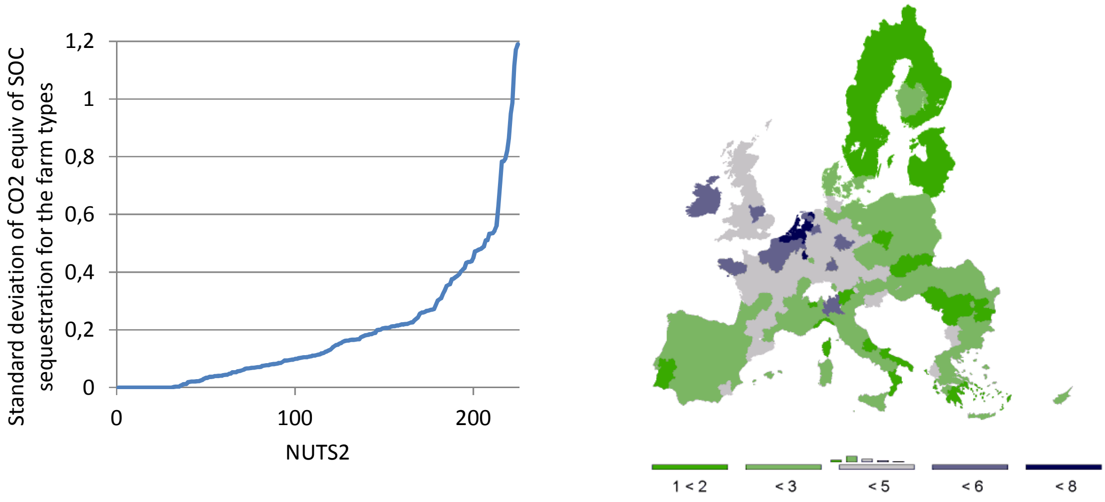
[13] SOC * 44/12 = CO2e

To better understand the variation, introduced by approximating the location of the farm type models,

Figure 1 B) presents the standard deviation of the annually CO_2e in each NUTS2 region (presented at the horizontal axes). We observe in 85% of the NUTS2 regions a spread of SOC rates up to 1.2 t of CO_2e/ha/year. This variation clearly shows that the farm types are closely linked to soil and other agro-ecological factors and hence sequestration rates are heterogeneous. Nevertheless, for about 15% of NUTS2 regions no difference between the sequestration rates exists, e.g. regions with similar soil conditions, as in parts of the Netherlands, and/or a very homogenous agricultural production structure.

Figure 1: A) Standard deviation of CO2e of C sequestration for the farm types in the EU27; B) CO2e of C sequestration per hectare aggregated at NUTS2 level

A) **B)**



2.2 Modelling grassland in CAPRI

The scenario was implemented, allowing farm types in a NUTS2 level to commit different levels of grassland increases depending on their economic marginal costs. The cost depends on the marginal revenues of arable and grassland activities of all the farm types (due to differences in yields, costs and premiums). The regional resolution at NUTS2 level for the obligation was chosen because the greening obligations of the CAP for grassland in some member states[14] or certain RDP programs allow that in a region farmers might convert arable to grassland whereas others can decrease grassland (as long as the constraint complies at regional level). In addition, the change of agricultural land needs to be considered when calculating SOC changes. As changes in revenues can result in renting or leasing land, this land use change needs to be considered for the SOC accounting. Grassland increase which origins from "other land uses" than arable land are not accounted as additional carbon sequestration. This is justified by the similarity of natural grassland to managed grassland and therefore the lowest implementation costs (i.e. compared to forestry)[15]. How much land is used for agriculture is defined in the economic model by the land supply function which depends on the marginal revenue to land and is estimated from three sources: (i) the potential available land for agriculture (ii) parameters related to the agricultural land supply elasticity and (iii) the land transformation between different land types (Jansson et al., 2013). The farmer's decision on whether to increase grassland depends on the costs and the amount of the premiums. To technically implement this in the model we have changed the premium as long as the 5% at the regional level was achieved, which results in NUTS2 specific grassland premiums[16]. We are calculating two forward looking simulations: The first is a business as usual[17] scenario while the second simulation imposes a 5%

[14] The restriction of the greening EFA (Ecological Focus Area) measure is applied in some MS at regional level.
[15] The economic model is based on the agricultural statistic from EUROSTAT. As Geo-data from CORINE report a lot more grassland vegetation than reported in the statistics, we can assume that additional rented land for fulfilling the grassland obligation comes mainly from natural grassland. This also means that no additional SOC should be accounted for this land use change.
[16] This premium needs to be financed by tax payer and is therefore equal to the costs for calculating the CO_2 abatement cost.
[17] In the reminder the business as usual is also called "baseline".

increase of grassland. The effects are quantified by comparing the scenario against the business as usual scenario. The model evaluates the differences in land use, income, supply and trade as well selected environmental indicators. Based on the premiums (tax payer costs) and the farm type specific sequestration from the CENTURY model we can derive abatement costs.

3 Results

The result of the applied economic model is the consequence of manifold endogenous adjustments at different regional scales. The reaction of the farmer is endogenous and driven by the economic principles to behave in a cost efficient way. Furthermore the market clearing condition that supply meets demand is achieved by endogenous prices, which in turn affect farmers. In addition adjustments on the land market needs also to be considered. We proceed by analysing first the land use and then the economic effects such as price change, income and change in trade. Afterwards we analyse the emission changes and the abatement costs. We present the results along two regional dimensions: The official territories at MS and NUTS2 and the farm types, whereas farm types are aggregated at MS or EU level or presented as a distribution over the complete population.

3.1 Land use and animal heard size changes

One could expect that the grassland expansion comes exceptionally from arable land. However, farmers bring also other land into cultivation to reach the 5% conversion target. In Table 3 the results are presented for the farm types at EU level. In total grassland area increased by 2.9 Mio ha, of which 1.7 Mio ha comes from arable land and 1.2 Mio ha from non-agricultural land[18]. In addition, farmers reduce activities which can be substituted by the additional fodder on the increase in grassland. We observe a 28% decline of fodder crops on arable land. The reduction does not avoid that cereals (-30%), oilseeds (-5%) and other crop on arable land (-2%) are also reduced (data not shown). In total 7.5% of the fallowed land and set-aside[19] in the EU is reduced, which account for almost 50% of the reduction of arable land in the farm types 'Sheep, goat other grazing livestock', 'Cereals oilseed and protein' and 'Mixed livestock'.

The increase of grazing areas and grass production results in an increase in cattle and sheep herds. Poultry and pig herds are decreasing for the pig and poultry farm type as feeding costs increase due to higher cereal prices. Farm types with specialisation in 'sheep, goat other grassing livestock' account for almost 30% of the grassland expansion followed by 'cattle rearing and fattening', 'dairy', the 'residual' and the 'mixed crop livestock' and 'cereals, oilseed and protein crops' farm type. These farming systems account for almost 86% of the grassland conversion. Permanent farm types as vineyards and fruits have high opportunity costs and are less predesignated. The regional distribution of converted grassland is depicted in Figure 4.

[18] This became profitable due to the incentives of the grassland premium.
[19] Fallowed land and set-aside are land use classifications on arable land as there are part of the crop rotation.

Table 3: Land use change in EU and the EU-aggregated farm types

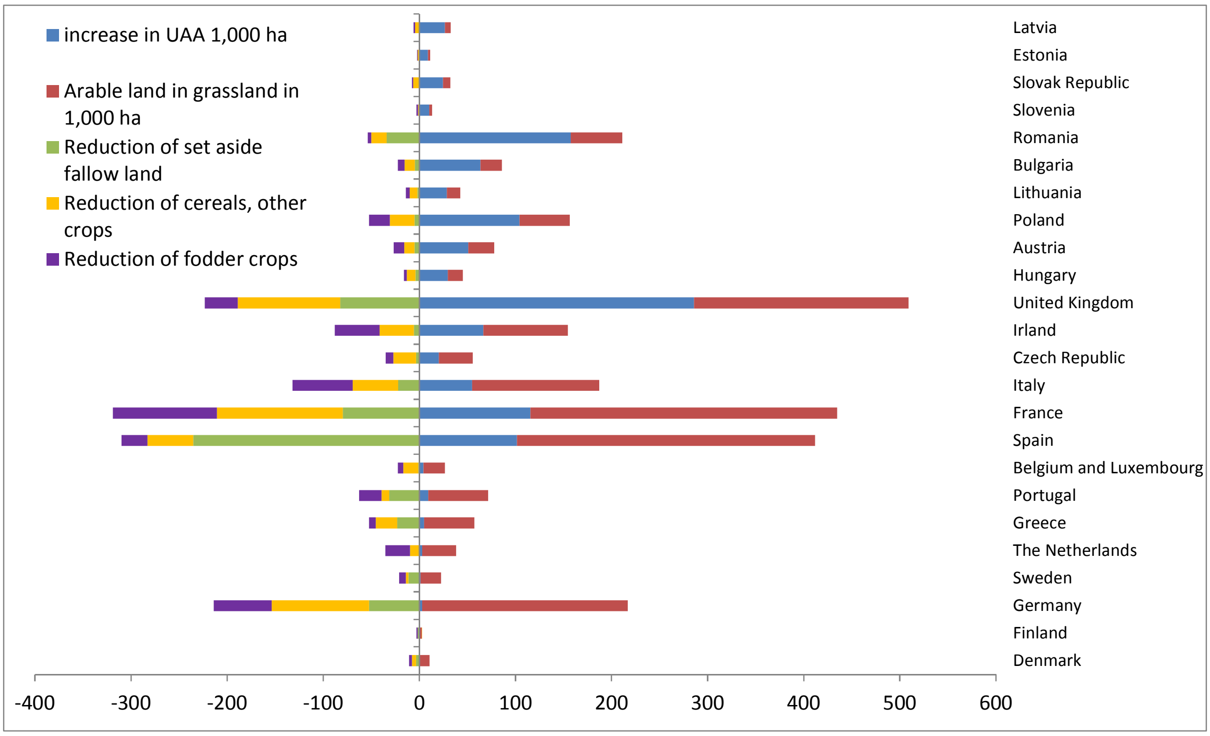
			Grassland		Arable land					Animal	
Type of farming (FT)	Abbr.	Utilized agri. Area (UAA)	Pasture	Share conv.	Arable land	Cereal	Other crops	Set aside fallow land	Fodder crops	Cattle	Other
					1,000 ha					Livestock Units	
EU	Abs. diff	**1,176**	**2,909**	100	**-1,733**	-528	-120	-610	-476	174	26
EU percentage change	%	**1**	**5**		**-1**	-1	-.3	-8	-2	.3	.
Sheep, goat other gra.	44	532	**777**	**27%**	**-245**	-41	-4	**-127**	-73	32	25
Cattle rearing fattening	42_43	184	409	**14%**	-225	-64	-8	-52	-102	49	.
Dairy	41	106	358	**12%**	-252	-82	-8	-39	-123	23	-2
Residual	RES	94	337	**12%**	-242	-90	-26	-61	-65	13	-2
Mixed crops-livestock	8	82	321	**11%**	-238	-90	-22	-82	-45	22	1
Cereals oilseed protein	13	60	312	**11%**	**-252**	-76	-29	**-125**	-23	16	7
Field cropping mixed	14_60	66	221	8%	-155	-53	-15	-59	-28	9	2
Mixed livestock	FT7	46	122	4%	**-76**	-23	-2	**-37**	-13	7	1
Pig and poultry	FT5	3	28	1%	-24	-5	-3	-14	-2	2	-6
Olives	FT33	.	13	.	-13	-2	-1	-9	-1	1	.
Vineyards	FT31	.	5	.	-5	-1	-1	-2	-1	.	.
Fruit and citrus	FT32	1	4	.	-3	.	-1	-2	-1	.	.
Permanent combined	FT34	.	3	.	-3	-1	.	-2	.	.	.
Horticulture	FT2	.	.	.	.	.	.	.	.	.	.

. = less than 0.1

The conversion of arable land into grassland can sequestrate additional carbon into the soils, however, if additional land is rented (which was not in agricultural production before) to satisfy the grassland obligation, no additional C sequestration occurs as the converted land is assumed to come mainly from natural grassland (and therefore with similar carbon sequestration rate than the managed grassland). However, because the grassland premium is paid to all grassland converted this affects the abatement costs negatively. The analysis presented in Figure 2 reveals that we can distinguish between four groups of MS. The Figure presents five different land types converted into grassland: arable land (red bars); newly rented land (increase in UAA – blue bars); and the green bars depict the reduction of set-aside/fallowed land on non-productive arable land, the yellow bars the reduction of area used to cultivate cereals and other crops, and the purple bars for fodder crops. Logically, the yellow, purple and green bars summed up show the same lengths as the red bars. The MS are ordered by the ratio of arable land relative to land brought into cultivation (increase in UAA and reduction of set-aside/fallowed land). Denmark, Finland, Germany, Sweden, the Netherlands, Greece, Portugal and Belgium Luxemburg are the regions in the first group. These countries convert mainly arable land, whereas the share of set-aside conversion is small. In those regions land prices[20] are high (Figure 3) and in combination with a medium until low buffer of potential new UAA this yields in a conversion of arable crops into grassland.

[20] Land prices are the shadow value of the shadow values of the total UAA land constraints in the model

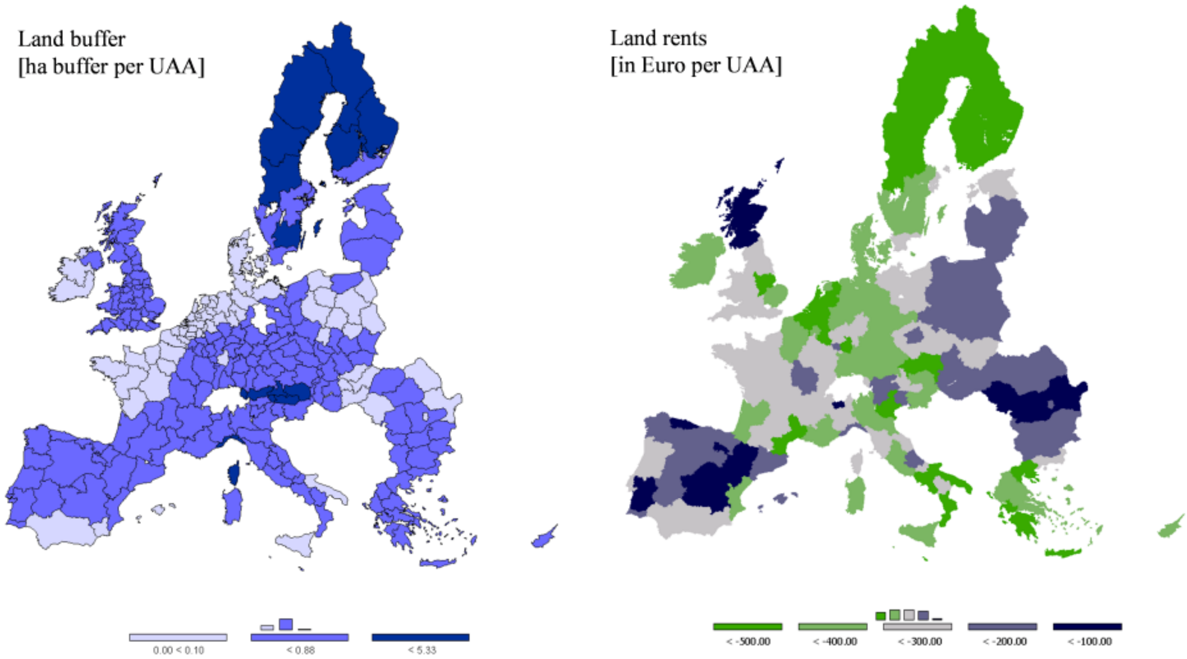
Figure 2: Land use changes at MS level - sorted by ratio of arable land relative to land brought into cultivation



Malta and Cyprus are not shown because values are too small to display

Farmers in Spain, France and UK (the second group), have due to their initial share and extend of grassland (around 30%), the highest obligation with the policy scenario. They use set-aside and convert it into grassland or rent land as land buffer exists and can be hired for comparable low prices than further reducing cash crops from arable land. Ireland is a special case. The high grassland shares (75% on UAA) results in a high pressure to achieve 5% of the grassland. However, land buffer rarely exists and rents are high (Figure 3) and it comes along that set-aside is rare. Because the target is obligatory the regions in Ireland have high costs and need to get compensated by high grassland premiums (>400 EUR per hectare). The story for Northern Ireland (82%) is similar. Whereas the rest of UK with high grassland shares particular in Scotland (85%), Wales(88%), North East (70%), North West (77%) and South West (62%) face lower cost to cultivate new UAA and a land buffer exists. The remaining countries (the third group) belong mainly to the new MS states and rent more land than converting existing arable land due to the combination of a high land buffer and low renting costs.

Figure 3: Land buffer and prices aggregated at MS level



3.2 Changes in supply, income and prices

In

Table 4, we show the changes in supply, revenue, costs and agricultural income aggregated at EU-farm type level. We can observe an effect on the supply of crops and livestock, but only marginally. The supply of crops is decreasing at EU level and in all farm type EU-aggregates, but not as much as would have been expected due to the fact that relatively little arable land is converted to grassland. The supply of total fodder activities is increasing (1%). It is interesting to highlight that while the supply of grass, grazing activities and pasture is increasing; the supply of fodder maize, fodder root crops and other fodder on arable land is decreasing (data not shown). Also the supply of cereals is decreasing due to the loss of arable land. Even though the supply of livestock is not changing at EU level, in some farm types it is increasing marginally (by less than 1%). The revenues of agricultural production increase very slightly at EU level by 409,000 EUR (0.08%). They increase the most for the farm types 'sheep, goat and other grazing livestock' (by 0.5%), followed by 'Cereals oilseed' (0.4%) and 'Field cropping' (0.3%). The increases in revenues are mainly due to the increased prices for crops (shown in the following chapter) and the increased yields in pasture. There occur also decreases in revenues for three farm types, which are however not relevant (less than 0.1%).

Table 4: Change in Supply, Revenue, Costs and Agricultural Income in EU and the EU-aggregated farm types

Type of farming (FT)	Supply crops excl. Fodder	Supply live stock	Revenues	Cost	CAP Premium	Grassland premium	Factor Income	Factor income incl. Premium
	% change		Change in Mio EUR					% change
EU	-0.5	.	409	411	33	417	448	.2
Cereals oilseed	-.2	.3	163	-9	-2	55	225	**1.1**
Field cropping	-.2	.1	97	8	1	30	120	.4
Horticulture	.	.	1	.	.	.	1	.1
Vineyards	-.1	.	5	-1	.	1	7	.1
Fruit and citrus	.	.	.4	.2	.	1	1	.
Olives	-.1	.6	11	2	.	2	11	.1
Permanent	.	.1	2	0.1	.	1	2	.1
Dairy	-3	.	**-19**	113	-1	82	-50	**-.2**
Cattle rearing fattening	-4	.1	**-24**	23	5	64	22	.3
Sheep, goat other gra.	-3	**.5**	98	154	27	52	22	.3
Pig and poultry	-.2	.	19	58	-1	5	-35	**-.7**
Mixed livestock	-1	.	37	51	-1	**12**	-3	**-.1**
Mixed crops-livestock	-1	.	69	45	1	50	75	.6
Residual	-1	**.**	**-51**	**-37**	3	64	52	.1

. = less than 0.1

Total costs include costs for fertilizer, crop protection, feed, and other variable inputs

The CAP Premiums change in our scenario (due to land use changes), but only in an irrelevant dimension. Due to the grassland premium implemented in our scenario (in total 417 Mio EUR for the EU and on average 238 EUR/ha/yr), the agricultural factor income increases in the EU, however in relative terms only slightly (0.2%). 'Cereals and Oilseed' gain the most (1%) in income. Three farm types loose factor income, but only slightly: 'Pig and poultry'; 'Dairy' (due to decreased revenues and increased costs); 'Mixed livestock' (due to increased costs, decreased CAP premiums and only relatively little grassland premium).

The scenario leads to total EU welfare losses of 1 billion €. The primary losses are experienced by profits from non-agricultural land use and losses by consumers due to higher prices (1.3 billion €). Farmers gain from higher prices and additional premiums.

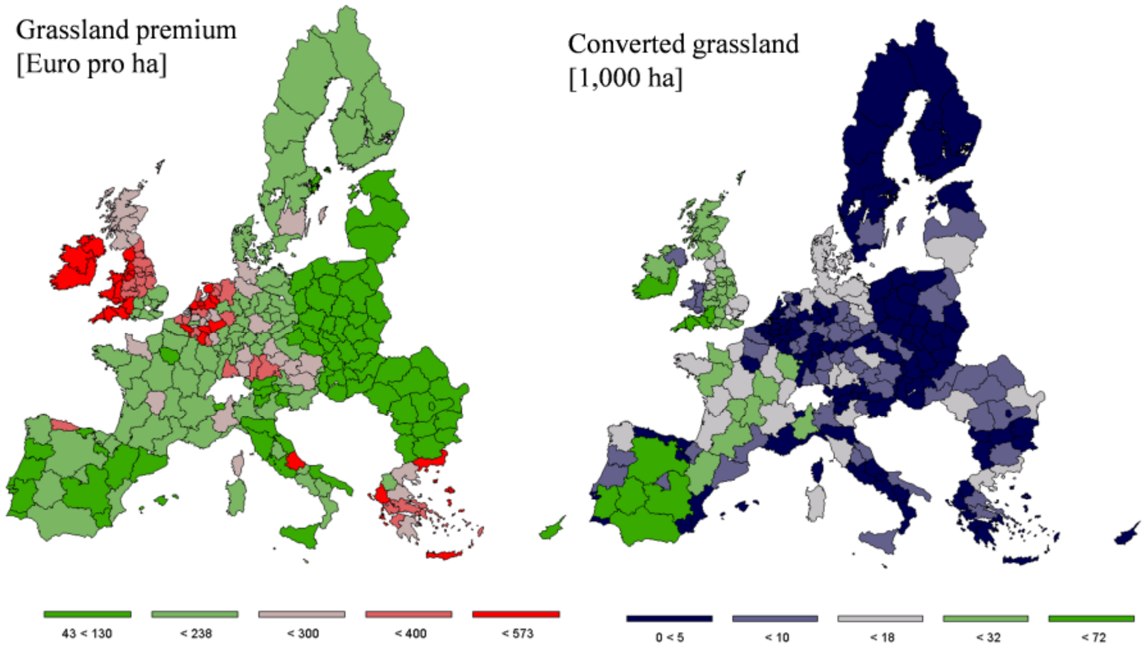
The change in supply triggers price adjustments as reported in Table 5. Overall we observe only moderate price changes. The additional supply of fodder from grassland and resulting increase of beef and sheep meat let prices slightly decrease. For pork and poultry meat, the price change is small but positive. The price for crops and oilseed increase as supply declined. Higher prices induce import from other countries into the European Union, whereas lower prices increase exports. The export of beef meat is increasing by 5,000 t (1%), of sheep and goat meat by 1820 t (2%). Imports of Poultry meat are only slightly increasing (860t, less than 0.1%) and exports slightly decreasing (2180 t, 0.1%). Due to the rising prices for cereals and oilseeds, these commodities are increasingly imported into the European Union (cereals by 468,550 t, 1.5%; oilseeds by 179,510 t, 0.7%) and less exported (cereal by 515,610 t, 1%; oilseed by 16,770 t, 0.3%).

Table 5: Relative change in producer prices in the EU27 compared to baseline

Agricultural commodity	Relative change	Agricultural commodity	Relative change
Fodder	-0.5%	Other arable field crops	0.42%
Sheep and goat meat	-0.5%	Cereals	0.63%
Beef	-0.4%	Oilseeds	0.84%
Poultry meat	>0		
Pork meat	>0		

In Figure 4 **Error! Reference source not found.**is presented the regional distribution of the value of the premium and the area converted at NUTS2 level. The heterogeneity is very high (from less than 50 EUR/ha to 1000 EUR/ha). It can be highlighted that 50% of the area converted has a cost (equivalent to the premium calculated) below 200 EUR/ha of converted grassland

Figure 4: Grassland premium and converted grassland at NUTS2 level

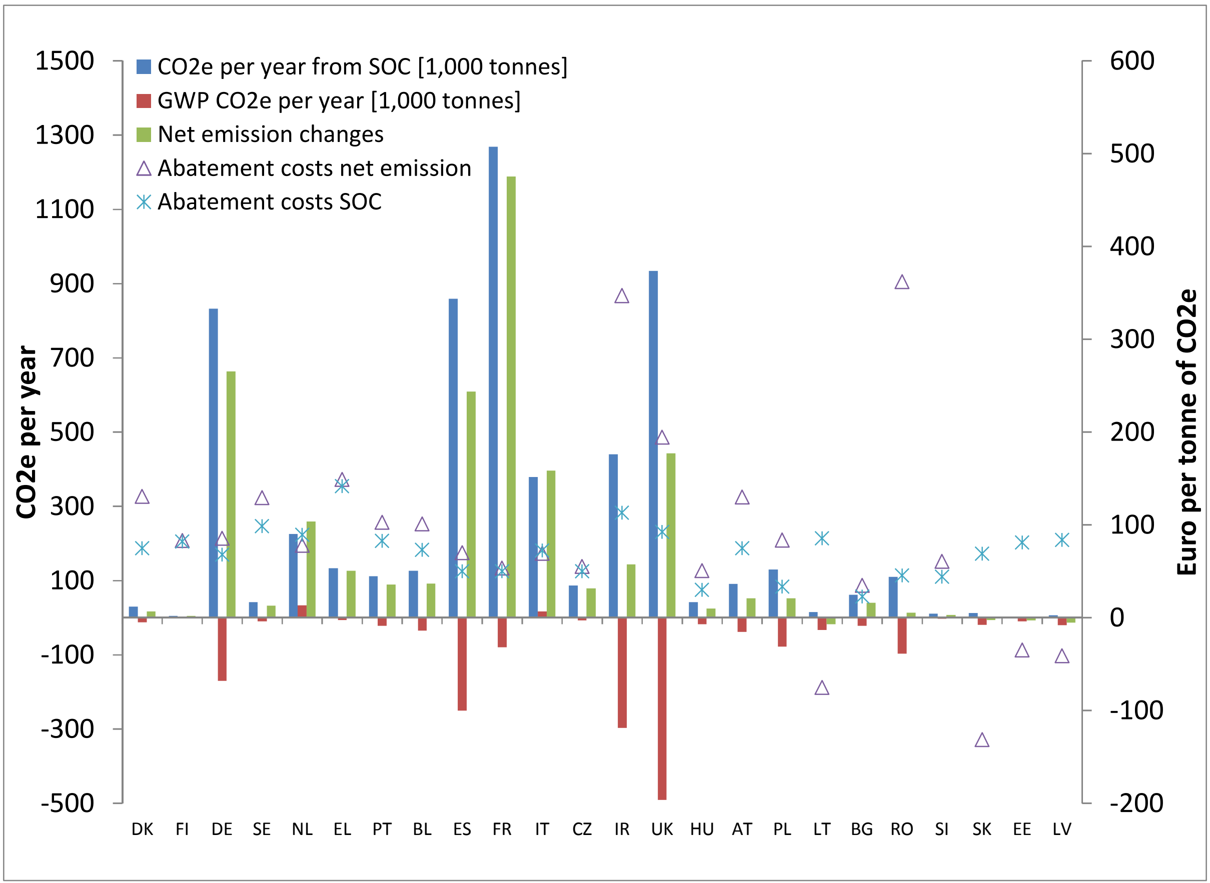


3.3 Emissions and Abatement costs

In total 5.96 Mio t CO2e emissions are accumulated into the soil per year by carbon sequestration in our scenario in the EU. This is offset by 1.75 Mio t CO2e from CH4 and N2O emissions (0.92 from CH4 and 0.83 Miot from N2O) coming from grazing livestock activities and fertilizer management. This results in a net-emission reduction of 4.3 Mio t CO2e. Figure 5 presents the emission changes at the MS level. The MS are ordered according to the ratio of rented land to reduction in arable land, as done in

Figure 2 for land use. The blue bars indicate the CO2e from sequestration whereas the red bars indicate the emissions of N2O and CH4 in global warming potential released from ruminants and land use changes. In Germany the increase of cattle and in Spain, United Kingdom and Ireland also the land use changes are responsible that the positive SOC sequestration effect on GWP (Global Warming Potential) is reduced by additional emissions in agriculture. Although in most countries the net-effect of emissions in agriculture is positive (green bar) for Latvia, Estonia and Slovak Republic the net-emission in agriculture becomes negative.

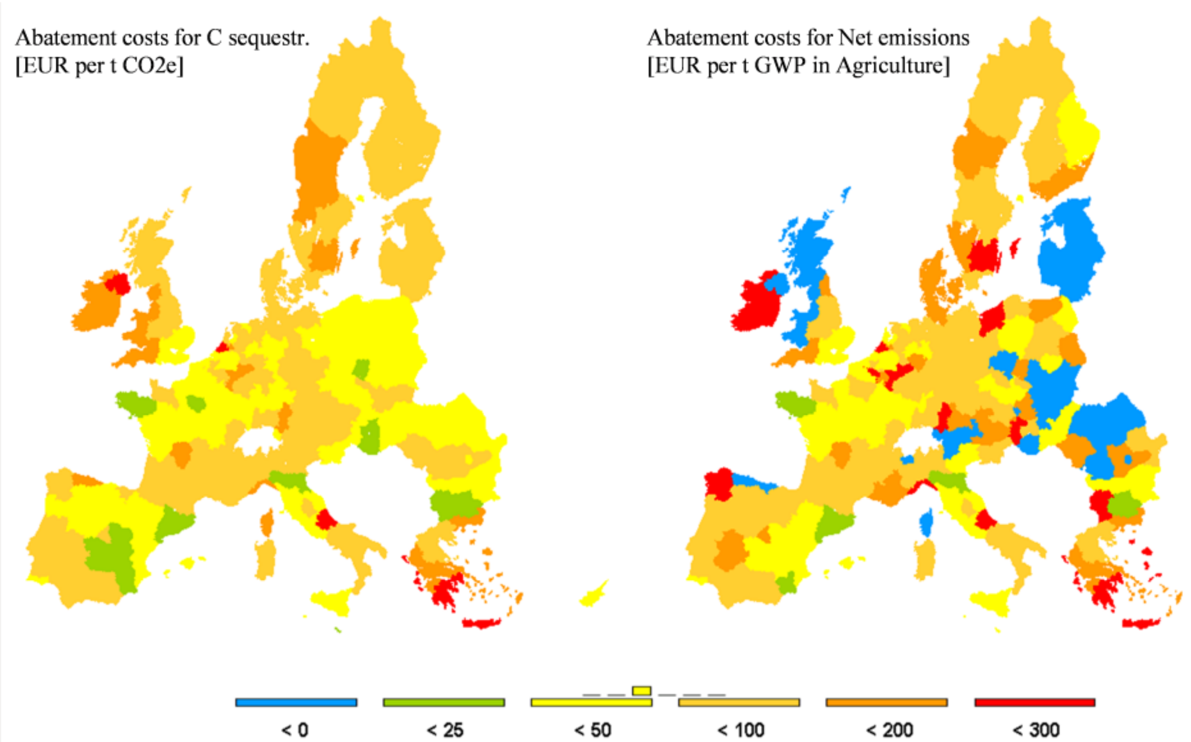
Figure 5: Emissions and abatement costs by MS



By calculating the ratio between the grassland premiums and the emissions, we can present the abatement costs for SOC sequestration and the net-emission. Abatement costs are the cost needed for reducing or avoiding the emission of CO2e to the atmosphere and are calculated as the total amount of grassland premium divided by change in CO2e emissions. The cost in our setting is equal to the money the policy needs to spend as grassland premiums, as it is usually tax payer's money. As a promotion of grassland leads to an increases in herd size and brings additional land into cultivation (as discussed above) the emitted amount of CH4 and N2O generally increases. This in turn results in higher net-abatement costs compared to the abatement costs for reducing GHG emissions through carbon sequestration. This effect is depicted in Figure 5 where the abatement costs for SOC are presented as triangles and the net emission abatement costs are depicted by crosses.

Figure 6 presents the abatement costs aggregated at the NUTS2 level, whereas the left hand side map depicts the SOC abatement costs and the right hand side map the regional distribution of the higher net-emission abatement costs. Blue areas indicate negative net-emissions.

Figure 6: Abatement Cost for SOC Emissions and Net-Emissions at the NUTS2 level



We observe negative net emissions in some regions of the UK and Spain and France. These regions are clearly cost-inefficient in saving GHG emission. The increasing emissions are the result of three effects. First the distribution of ruminant in the EU and its increase due to the additional supply of fodder subsidised by the policy, which increases methane and also N2O emissions. The second reason is the low SOC rates due to soil and climate conditions particular in regions such as LT, SK, EE and LV (indicated in Figure 1 right map) and the last reason is the increasing N2O emissions due to the cultivation and hence fertilisation of new land as observed in UK, IT and Spain, an effect which is indirectly the outcome of the market situation for land.

In Figure 6 we observe that most of the regions have abatement costs in between 25-100 EUR per ton of CO2e. However, besides the costs also the absolute amounts of GHG savings needs to be considered. For indicating this we use the abatement cost curve, which along the x-axes also presents the absolute amount of GHG mitigated. Note that values at the negative part of the x-axis indicate additional emissions. In Figure 7 marginal abatement costs curve is depicted. The charts of the first column summarize all EU27 farm types. The second column indicate the same aggregations but for the subsample at EU15 and the last column at EU12. The chart in the first row is aggregated by MS, the second by farm specialisation and the third by economic size class. Considering the chart at EU27 for the MS aggregation levels (column 1, row 1 of Figure 7) the overall net emissions of 4.3 CO2e emissions are depicted at the x-axis in 1,000 CO2e.

The corresponding EU15 and EU12 chart at column two and three indicate the relation between EU15 and EU12. Only a small part of the net- emission reduction (0.175 Mio t CO2e) comes from EU12. Actually although they save 0.2 Mio t of CO2e in SK, LT, LV, EE and MT emissions are additionally produced. The small contribution of GHG savings from EU12 is relates to the low SOC rates in this regions, as depicted in Figure 1 and that UAA increases are higher (0.9%) compared to EU15 (0.5%). The abatement costs in Figure 7 are up to 400 Euro pet ton CO2e for Ireland and Romania. Although almost all EU12 MS (except Romania) provide a reduction in GHG at costs below 83 EUR/t CO2e (highest costs Poland) the absolute contribution is small. The major contributors are France, Italy and Spain, the Netherland and Germany, which can provide almost 2/3 of the 4.25 Mio t emission reduction at costs below 85 EUR (highest in Germany). The abatement costs curve stratified by the type of farming is depicted at the second row for EU27 (column 1) and EU15 (column 2), EU12 (column 3) in Figure 7. It is interesting to observe that the farm type specialized in cereals and protein crops (FT 13), mixed field cropping (FT 14/60), specialized granivores (FT5) and the mixed crops-livestock farming have the highest potential (2/3 of the overall GHG savings) to relatively low costs to save GHG. This is the case at the EU15 and EU12 level. The reason is that in such farming system rather arable land was converted than new land purchased or leased. The increase in UAA at the EU27 level for these farming systems range between 0.14-0.26%. Compared to that the farms specialized in dairying (FT41), cattle + dairying rearing, fattening (FT42_43) and sheep, goats and other grazing livestock (FT44), which have 1/3 of the mitigation potential to higher costs, increase UAA up to 2.6%. Consequently other emissions from land expansion - emission related to fertilization - and from increase of ruminants (up to 1.2% for FT44) using the addition cheap fodder area decrease the saving potentials and increasing abatement costs. If we compare the abatement costs between EU15 and EU12 across the farm specialisation (column 2 and 3, row 2) we observe lower costs for those farm specialisations which save GHG in the EU12 (FT13,FT14/60, Residual, FT8) and higher abatement cost (FT44), even negative for grazing and dairying livestock farm types (FT41, FT42/43 and FT7).

In the last column the abatement cost curve is stratified by the size of the farm. Lower production costs of larger farms (>100 ESU = above 100.000 Euro income per farm) result in lower GHG saving costs (83 EUR per tonne of CO2e) whereas smaller farms below 16 ESU (less than 16.000 EUR income per farm) have considerable higher costs (166 EUR per tonne of CO2e). As the share of small farms in the EU12 is higher the share of GHG savings in EU12 is higher compared to the share in the EU15.

Figure 7: Abatement Cost Curve for net-emissions at the EU27, EU15 and EU12 level for MS and farm specialisation and size class

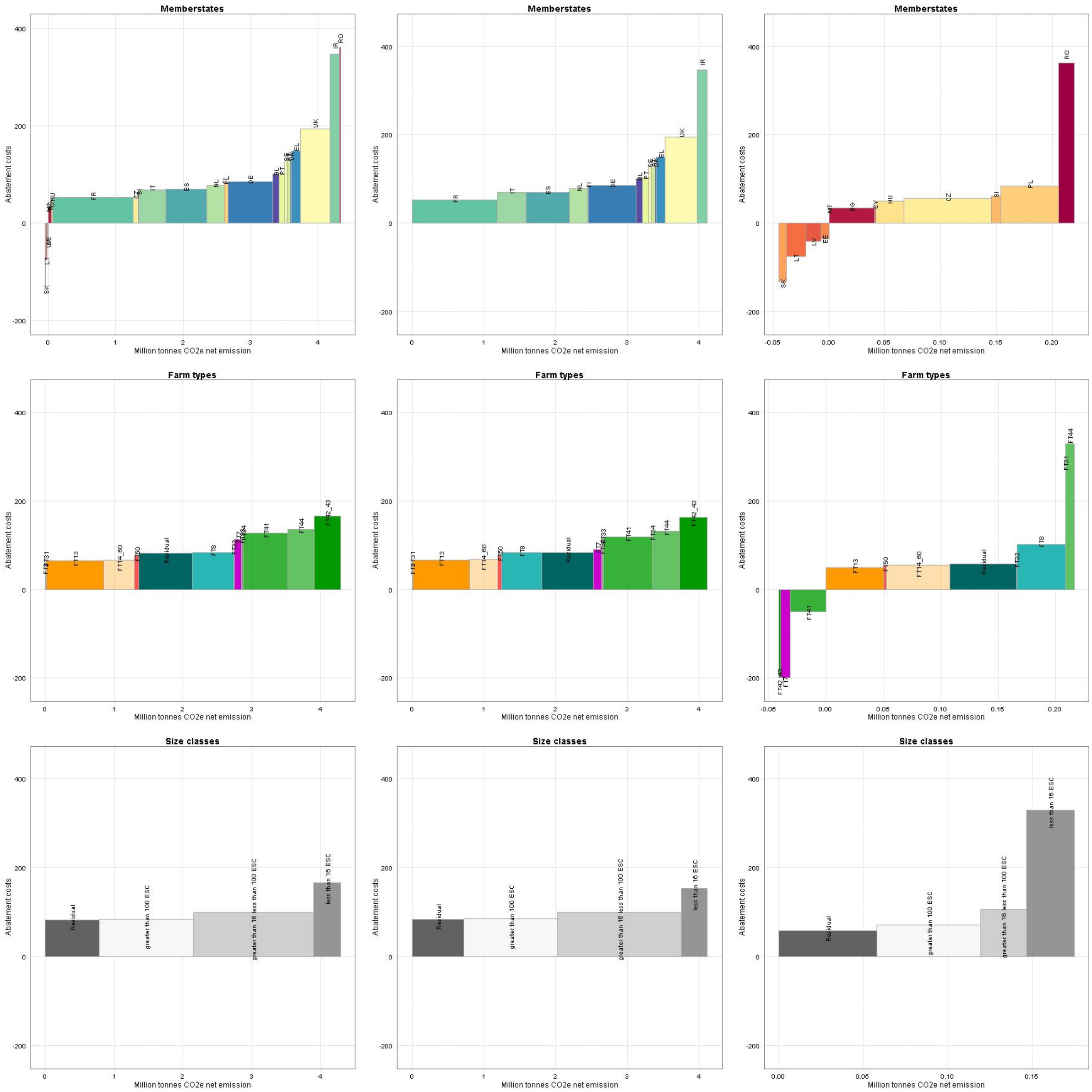
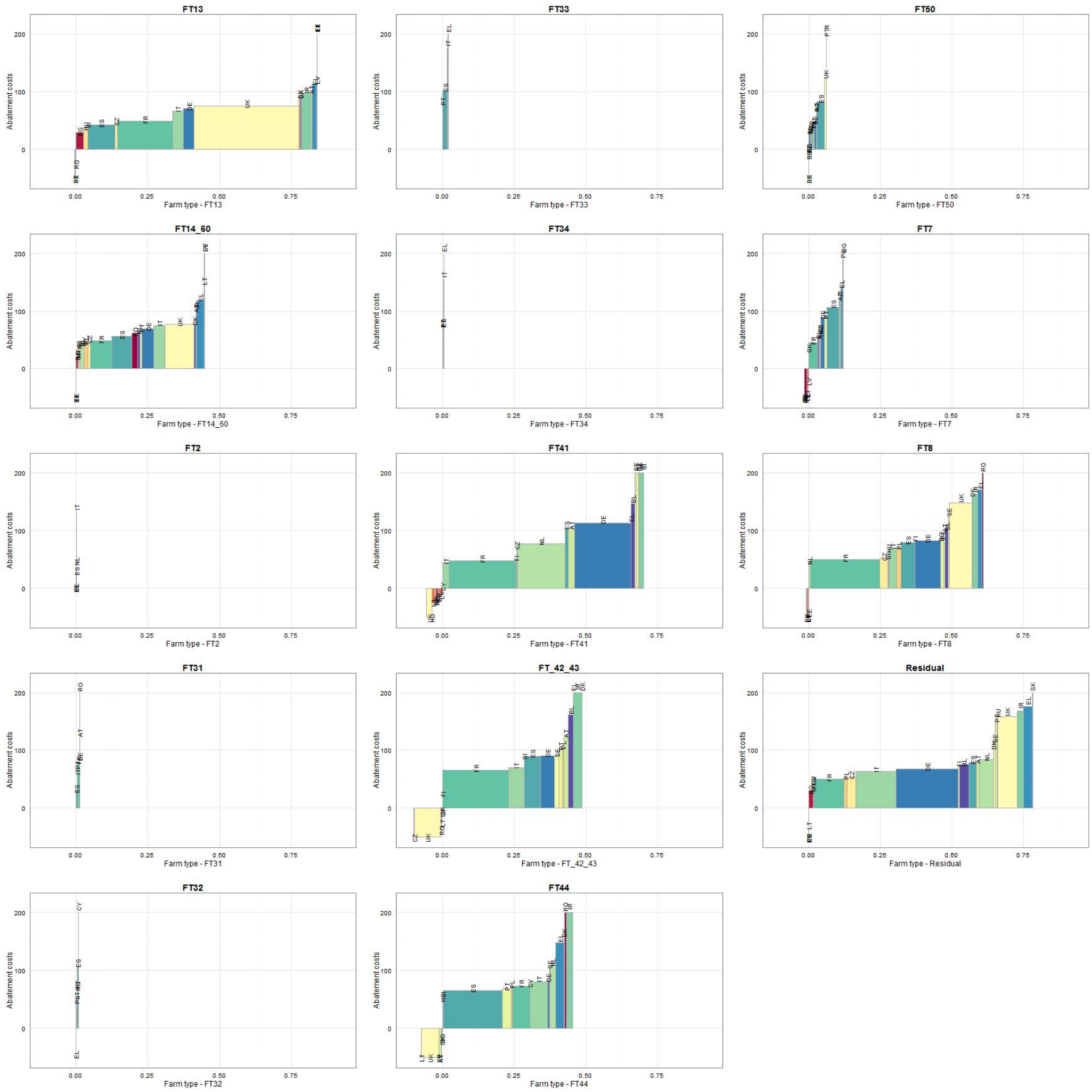


Figure 8 further disaggregate the abatement costs by farm specialisation at the EU27 indicate in Figure 7 (column 2, row 1). As example the orange rectangle for FT13 (0.84 Mio t CO2e, and 65 Euro abatement costs) is further disaggregated in Figure 8 (chart = column 1, row 1) by the contributions of the MS states.

The potential of GHG savings by farm types is indicated along the x-axis. A chart with small parts on the x-axis does only little contributes to the overall savings. We observe a wide range of abatement costs within the farm types across the MS. Abatement cost below 50 EUR can reduce GHG by 1.2 Mio t of CO2e. Mainly France contributes to this with farms specialized in crop mixed livestock production (FT8), dairying (FT41), cereals and protein farming and mixed crops (FT14, FT13/60). If the abatement cost increase up to 75 EUR additional 2.3 Mio t of CO2e can be reduced. This is mainly contributed by Spanish and United Kingdom cereals farms (FT13) and Spanish mixed crop farms (FT14/60). In addition, Spanish sheep and goat farming as well as the residual farming types in

Germany and Italy. For abatement cost below 80 EUR almost 3.2 Mio t are saved whereas the Spanish specialized farms in cereal crops (FT13) and mixed crops (FT14/60) contribute to the major shares of the emission reduction as well as the cereal farms in UK goat and sheep farming in France.

Figure 8: Abatement Cost Curve for net-emissions for all farm types in the EU27 by farm specialisation (the colour indicates the MS)



4 Discussion

In this section, we summarize and discuss our results via comparing them to findings in the literature when available. We discuss the policy implication of a measure for GHG mitigation through grassland expansion and point to further research directions.

4.1 Validation of the results

To analyse if grassland expansion in Europe can be an appropriate policy measure for climate change mitigation, in our work we not only consider GHG mitigation through carbon sequestration in grassland but also additionally arising GHG emissions through N2O and CH4 coming from increased grazing livestock activities and fertilizer management. The analysis show that the potential for climate change mitigation and the resulting costs depend on various factors. One factor, also shown by the literature (Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004), is the heterogeneity in the carbon sequestration rates. In this study, we used the biogeochemistry model CENTURY, which has a high spatial resolution. For the mapping of carbon sequestration rates (aggregated from the Century model to NUTS3 regions) to the CAPRI farm types (at NUTS2 level) we have used the FADN data. Another influencing factor, to our knowledge not discussed so far in the literature, is the behaviour of farmers regarding how the grassland expansion is achieved through land use changes, because additional carbon is only sequestered if arable land is converted to grassland. Our analyses show that in Europe 1.2 Mio ha of the 5% grassland increase is achieved by taking other land into cultivation. This additionally cultivated land releases GHG emissions through fertilizer application and does not sequester additional carbon. The regional effects differ and are influenced by the availability of additional land (land buffer) and costs for renting land. The third influencing factor on the effect of potential climate change mitigation is the agricultural production structure and therefore the type of farming which is reflected by the different farm types in CAPRI. Especially high grassland shares, high shares of set-aside and fallowed land, as well as fodder on arable land, which could be converted into grassland at low cost, reduce the potential for climate change mitigation. These three factors result in a regionally highly differentiated adaption reaction.

The overall net effect in Europe simulated with the model is a reduction of 4.3 Mio t CO2e (as 7-year average) when converting 2.9 Mio ha into grassland. This is achieved by grassland premiums and hence costs of about 417 Mio EUR but also increasing prices for consumers and resulting welfare loss of 1 bn EUR. The net abatement costs based on the premium payments account 97 EUR/t CO2e.We have not found any literature or study which quantifies the net emission changes in our context but we can compare the C sequestration with the findings of Freibauer et al. (2004) and Vleeshouwers and Verhagen (2002). They calculated 11.8 Mio t CO2e at EU15 level[21]. This can be compared to 5.5 Mio t CO2e in EU15 in our analysis. Our value is two times lower. The main reason is that in our model we also consider land market effects, therefore also additional land through land buffer can be converted[22] but this land is not an additional C sink. Another reason might also be the explicit spatial representation of C sequestration rates for the farm types. A comparison cannot be made directly as the data in Vleeshouwers and Verhagen (2002) is not presented at disaggregated level.

Comparing our results further, it shows that the reduction of GWP represents about 1% of the total CO2 emissions from agriculture in the EU28[23]. The induced costs of 417 Mio EUR correspond to 3.1% of the annual EU Rural Development spending for the period 2014-2020 (13.6 bn EUR). We calculated an average per-ha premium of model 238 EUR/ha/yr. Summing this up for a whole RDP programming period of seven years, it amounts to an investment of 2.9 bn EUR. If such a large sum of tax payers' money is spent, the question arises, what happens after the program has expired? Since farmers produce higher profits through arable use of land, the grassland would certainly be re-

[21] They quantified 5.3 t CO2e/ha/yr for C sequestration to grassland in the EU-15 which results for 2.2 Mio t CO2e in our analysis in 11.8 Mio t CO2e.

[22] Carbon sequestration rates as the managed grassland is also similar to forest (Murty et al., 2002; Gou and Gifford, 2002)

[23] 469 Mio t CO2e according to EEA (2014)

converted to arable land and hence the sequestered carbon would be emitted again. To prevent this, a ban on conversion has to be imposed (which would however certainly reduce the willingness of farmers to join the grassland measure) or a prolongation of the measure and hence more money would be needed. However, as also pointed out by Freibauer et al. (2004) and Lugato et al. (2014), it should be kept in mind that carbon sequestration in soils is not linear over time. The highest rates of carbon sequestration occur during the first years after conversion, and a new equilibrium is reached after between 20 and 100 years. It should therefore be noted that the marginal costs per t of mitigated CO2e will rise with increasing age of the increased grassland, if the grassland premium is paid over a longer time horizon.

The yearly abatement costs depend on the amount of premium that needs to be paid so that farmers have the incentive to convert grassland and this in turn depends on the economic situation (yields, costs, land rents and land markets), which determines the land type converted to grassland and if arable land is converted additional GHG emissions will occur whereas soil and climate conditions indicated by the C sequestration rates further determine the level of abatement costs. The average net abatement costs account in our study 97 EUR/t CO2e. We observe that substantial carbon sequestration can be achieved from 50 EUR/t CO2e onwards. Abatement cost below 50 EUR can reduce GHG by 1.2 Mio t of CO2e. For abatement cost below 80 EUR almost 3.2 Mio t CO2e are mitigated. Comparing these values with other studies it shows that a number of studies assess the influence of conversion to grassland on carbon sequestration (As shown above) but without calculating the abatement costs. However, we can compare our results to studies which calculated the abatement costs for similar GHG mitugation measures in agriculture. Pellerin et al. (2013) found for France that the mitigation measure of increasing the life spam of grassland has even negative costs (-184 EUR/t CO_2e for accumulating 1.1 Mio t CO2e) due to less frequent ploughing and sowing of temporary sown grassland; for introducing grass buffer strips they found occurring costs of 528 EUR/ton CO_2e (for accumulating about 0.3 Mio t CO2e) due to the production losses as a result of planting grass buffer strips which reduce the production area. The authors base their findings on a literature review, statistical sources, and consulting expert groups. We can also compare our results to studies presenting the abatement costs for other GHG mitigation measures in agriculture that are not similar to our scenario. Pellerin et al. (2013) assessed the mitigation potential of the cultivation of legumes in grassland which reveals in negative costs (-185 EUR/t CO_2e) and the cultivation of grain legumes in arable systems at 192 EUR/tCO_2e. O'brien et al. (2014) found that, for the Irish agriculture, the introduction of cover crops would cost 50 EUR/t CO_2e. Röder et al. (2015) found for Germany, regarding the same mitigation potential as in our Scenario (6 Mio t CO2e for EU27), abatement costs for production of short rotation coppice of 27-33 EUR/t CO2e, for restoration of peatland 0-5 EUR/t CO2e, and for energy maize production about 70-75 EUR/t CO2e. It needs to be considered that in this study the direct and indirect land use effects and leakage effects as well as costs for engineering and planning were not considered. The overall potential for GHG mitigation were calculated as up to 50 Mio t CO2e only for Germany, this is ten times more than we have calculated for the whole EU27. It is questionable if a scenario demanding more than 20% of the agricultural land in Germany can be implemented practically by policy makers. Moreover in their analysis, it was assumed no price effects for products and land markets occur, which is also a strong assumption. A realistic assumption is that higher production prices will be induced which will intensify the existing agricultural production and increase fertilizer inputs and hence emissions. Marginal revenue for land will increase and the additional land will also release emissions. Henseler et al. (2015) present abatement costs of 100 EUR/t CO2e for mitigating 12 Mio t CO2e by the production of short rotation coppices in Germany. We can furthermore found studies on abatement costs for GHG mitigation options in agriculture considering an overall mitigation target. De Cara and Jayet (2011) present an equilibrium emission price of 32-42 EUR/t CO2e to meet the 10% abatement target in the EU through adjusted production decisions of farmers regarding crop area allocation, animal numbers, and animal feeding. The authors use a model based on FADN data, different farm types by a set of 1307 independent mixed integer linear-programming models, and a set of constraints. Osterburg et al. (2009) reviewed different studies concluding that in the EU for agricultural scenarios abatement costs of 20-30 EUR/t CO2e are assumed, partially even 50 EUR/t CO2e. Furthermore, they also reviewed studies on abatement costs showing that for first afforestation costs in Germany account to 33 EUR/t CO2e (only for the premium) at least. The comparison shows that the majority of studies report lower abatement costs, particularly for other measures like restoring peatlands, afforestation. The comparison between different studies is difficult because the applied methodologies vary greatly and are not always described sufficiently. That our costs are higher results also partially from considering direct land use and herd size effects and for certain FTs price feedbacks from the markets as well as indirect GHG emissions. Nevertheless, we also found regions and FTs with costs below 50 EUR/t CO2e. However, these regions could not abate a relevant amount of GHG emissions.

4.2 Political implications

4.2.1 Legal framework

The analysed scenario in this paper could be implemented as policy measure in the first or second Pillar of the CAP. Under the first pillar of the current CAP after 2013[24], the Direct Payment regulation and particular the greening measure for permanent grassland regulate that grassland should be maintained, and if the farmers do not comply, they lose a certain part of the direct payment (greening payments). This policy targets to maintain grassland but will certainly not increase grassland. To further increase grassland in the frame of the first Pillar of the CAP, the MS have the possibility to include the conversion from arable to grassland as Ecological Focus Area (EFA). The EFA can be implemented for up to 5% during 2015-2017 and increased until 7% from 2018 onwards. Under the second pillar of the CAP the mitigation measures “Agri-Environment Climate Change measures (AECM)”, embedded in the Rural Development Regulation (OJEU, 2013b), aim to promote positive contribution to the environment and climate. These measures, compared to the greening measures, are optional for the farmers and are differently designed in the RDPs by the MS or even at a lower regional administrative level and need to be co-financed by the MS. In addition, if farmers participate, they are obliged to contribute over a certain period (mostly 5-7 years), which depends on the region and the program.

4.2.2 Targeting

Our findings clearly show that, if the reduction of GHG emissions is the major objective of the policy, the “one fits all” approach chosen in the modelling exercise is not an appropriate approach. This excludes an implementation of such a measure in the first Pillar of the CAP. To ensure a more efficient use of tax payers’ money, the measure would need to be more targeted and the following criteria would need to be considered as we have shown above: Where/for which FTs are the net-abatement costs the lowest? Where/for which FTs are the rates for carbon sequestration high? Where/for which FTs are additional emissions through N2O and CH4 low? Where/in which FTs would farmers be most willing to convert productive arable land into grassland? Many of these

[24] OJEU, 2013a; OJEU, 2013b; OJEU, 2013c

questions are already answered in the results above. It becomes clear that no region/FT is optimal in all criteria and compromises have to be found. However, we would recommend to target the grassland measure in France, Italy and Spain, the Netherland and Germany, which can provide almost 2/3 of the 4.3 Mio t CO2e emission reduction at costs below 85 EUR/t CO2e (highest in Germany). Generally, larger farms and farm types specialized in cereals and protein crops (FT 13), mixed field cropping (FT 14/60), granivores (FT5) and the mixed crops-livestock farming have the highest potential (2/3 of the overall GHG savings) to relatively low costs to save GHG emissions through grassland expansion. Being very precise, we recommend targeting the measure as follows (in descending priority): to Spanish and United Kingdom cereals farms (FT13) and Spanish mixed crop farms (FT14/60), Spanish sheep and goat farming as well as the residual farming types in Germany and Italy, Spanish specialized farms in cereal crops (FT13) and mixed crops (FT14/60), and cereal farms in UK goat and sheep farming in France.

4.2.3 Premium

For the yearly premium, we calculated an average of 238 EUR/ha/yr. This amount is 2.8 times higher than the average EU agri-environment expenditure for the period 2007-2009 which was 84 EUR/ha/yr (ESTAT, 2012), however it is within the range of the maximum premium per ha established for the "Agri-environment climate" measures in the CAP-Post 2013 (200-900 EUR/ha/yr) (OJEU, 2013b). An agri-environment scheme comparable to our scenario was offered e.g., in Germany North Rhine-Westphalia in the programming period 2007-2013 in the category contractual conservation management agreements "VNS2". In this scheme arable land had to be converted to grassland. The premium was 468 EUR/ha/yr. However, the major aim of this measure was not climate change mitigation but the promotion of biodiversity. As our results on abatement costs above show, from an economic point of view, it is not sensible to offer homogenous to all farmers. We recommend a tiered per-ha premium taking into account the different abatement costs presented above.

While designing the premium also other aspects need to be considered: on the one hand, costs associated with controlling and integrating such a measure imply transaction and control costs as well as increased administrative burden. McKinsey (2009) estimate the transaction costs for GHG mitigation measures in agriculture at on average approximately 1 € / t CO 2e. However, as pointed out by Osterburg et al. (2009), they are subject to uncertainties. On the other hand, additional with increasing grassland also positive side effects arise like increasing biodiversity (PBL, 2012). These should be considered as higher marginal benefit of the decrease in CO_2 emissions compared to the industry and energy sectors.

Since all agri-environment measures of the second Pillar of the CAP are offered at voluntary basis, the big question remains if the premium can attract farmers to participate. In addition, it should be considered that farmers' adoption of voluntary measures is not only driven by economic factors. Factors such as social capital, farmer's attitudes towards environment, farm structure, economic factors and farmers characteristics should be considered in case policy makers want to implement this policy.

5 Conclusion

The aim of this study is to analyse if grassland expansion in Europe can be an appropriate policy measure for climate change mitigation. For this, we linked the CAPRI model representing the EU farm types to the bio-physical model CENTURY which determines the carbon sequestration rates at a high resolution level. As far as possible, we compared our results to findings in the literature. This was only partially possible because to our knowledge no studies exist on C sequestration through conversion to grassland that cover the whole EU27 at high regional resolution and consider also the land market and take emerging additional GHG emissions into account. Furthermore, we embedded the results into the political context of the European CAP and GHG emissions and made suggestions for the design of a potential agri-environment scheme for GHG mitigation through grassland expansion.

Our results show that the potential and costs for GHG mitigation through carbon sequestration in expanded grassland is dependent on three major factors: First, the regionally highly different carbon sequestration rates; Second, the regional land market which differs regarding the available land buffer and land rents that in turn influence arising additional GHG emissions through land use change; And third, the regionally different predominant agricultural production which influences e.g., if additional GHG emissions through increasing livestock occurs or if arable land is converted to grassland and hence carbon sequestration is realized.

The overall net effect in Europe simulated with the model is a reduction of 4.3 Mio t CO2e when converting 2.9 Mio ha into grassland. This is achieved by a cost of about 417 Mio EUR. The net abatement costs based on the premium payments account 97 EUR/t CO2e, substantial carbon sequestration can be achieved already from 50 EUR/t CO2e onwards. Compared to other GHG mitigation measures like restoring peatlands or afforestation this would be a relatively costly policy.

From a spatial point of view we could show that the carbon sequestration would be most effective in France, Italy and Spain, the Netherland and Germany. Generally, larger farms and farm types specialized in cereals and protein crops, mixed field cropping, granivores and mixed crops-livestock farming have the highest potential to relatively low costs. As there exist regions with very high costs and low abatement potential (even negative), we can conclude that such a grassland policy to save GHG emissions by carbon sequestration should not be implemented through the first Pillar of the CAP but could be designed as a targeted AECS of the second Pillar in frame of the RDPs. However, the effect of such a policy is only long-term efficient if the incentive for the farmers is offered permanently. Otherwise a re-conversion into arable land with a rapid release of the sequestered carbon would occur. For an integrated assessment of an AECS grassland program additional benefits like increased biodiversity, reduction of soil erosion and in nitrogen surplus need to be considered and would clearly reduce the abatement costs.

For further research directions it should be considered that carbon sequestration in grassland depends on the grassland management, as shown by Conant et al. (2001). Murty et al. (2002) provide a comprehensive literature overview, identifying further factors influencing the soil carbon content after land-use change (initial soil carbon, litter chemical properties, climate, soil type, changes in microbial community, changes in soil nitrogen cycling). In our study, by using the biogeochemistry model CENTURY, we could consider the influencing factors soil quality and climatic conditions at a high resolution level in Europe. The inclusion of more influencing factors could be aimed in future studies, but the required data will be a critical challenge, since an EU wide coverage is rare (Freibauer et al., 2004). To further investigate our model approach, a potential alternative scenario definition would be to define, instead of the regional level, an effort share agreement between the MS to achieve the grassland increase of 5%. This would give more insides into the additional GHG potentials at low abatement costs for certain FTs in certain regions. We could even further extend this exercise by taking the emission abatement as target value in the model. However, both additional scenarios are difficult to implement from the political point of view. The first scenario as it assumes that GHG emission targets are defined by the EU and not by the MS, the second scenario because it is difficult to make it a practical measure for the CAP. To further develop the presented model approach on the long term, the integration of a carbon model such as CENTURY in the CAPRI model (for example running at the level of the Homogeneous Spatial Mapping Units, Leip et al., 2008) could be envisaged, either directly or – to decrease computing demand – as a meta model (Britz and Leip, 2009).

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Annex

Table 6: Land use change in EU-MS

	Grassland			Arable land					Animal	
EU-Member State	Utilized agri. Area (UAA)	Pasture	Share conv.	Arable land	Cereal	Other Crops	Set aside fallow land	Fodder	Cattle	Other
				1,000 ha					Livestock Units	
EU	1,176	2,909	100%	-1,733	-528	-120	-610	-476	174	26
Belgium + Luxemb.	4	26	1%	-22	-13	-2	-1	-6	5	-2
Denmark	.	11	0%	-11	-4	-.3	-3	-3	.6	1
Germany	3	217	7%	-214	-89	-12	-52	-60	20	-6
Austria	51	78	3%	-27	-9	-2	-5	-11	4	1
Netherlands	3	38	1%	-35	-8	-2	-.4	-26	-5	-2
France	116	435	15%	-319	-94	-37	-80	-109	-19	-2
Portugal	9	72	2%	-63	-6	-2	-31	-23	2	1
Spain	102	412	14%	-310	-38	-10	-235	-27	28	7
Greece	5	57	2%	-52	-18	-4	-23	-7	.	.7
Italy	55	187	6%	-132	-39	-8	-22	-63	-8	1
Ireland	67	155	5%	-88	-32	-3	-6	-47	63	5
Finland	.	3	.	-3	.3	.	-2	-1	-.8	.
Sweden	1	22	1%	-21	-3	.5	-11	-7	.9	.
United Kingdom	286	509	17%	-223	-79	-28	-82	-34	73	10
Czech Republic	20	55	2%	-35	-20	-4	-4	-8	.6	.2
Estonia	9	11	.	-2	-.9	.	-.7	-.6	1	.1
Hungary	29	45	2%	-16	-9	-.3	-4	-3	.5	.2
Lithuania	29	43	1%	-14	-7	-.7	-2	-4	3	.
Latvia	26	33	1%	-6	-4	-.2	-.3	-2	2	.2
Poland	104	157	5%	-52	-25	-.7	-5	-22	-1	-.4
Slovenia	10	13	.	-3	-1	.	.	-2	.	.
Slovak Republic	25	32	1%	-8	-4	-2	-.7	-1	1	.6
Cyprus	.4	1	.	-.3	-.1	.	-.1	.	.	.1
Malta	.	.	.	.	.	.	.	.	.	.
Bulgaria	64	86	3%	-23	-8	-3	-5	-7	.7	.5
Romania	158	211	7%	-54	-15	-1	-34	-3	1	8

. = less than 0.1

Figure 9: Agricultural Emissions from methane and N2O