The costs of drowning GHG-emissions in the peatlands
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An economic assessment of potential agricultural emission-reduction in the LULUCF sector

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Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

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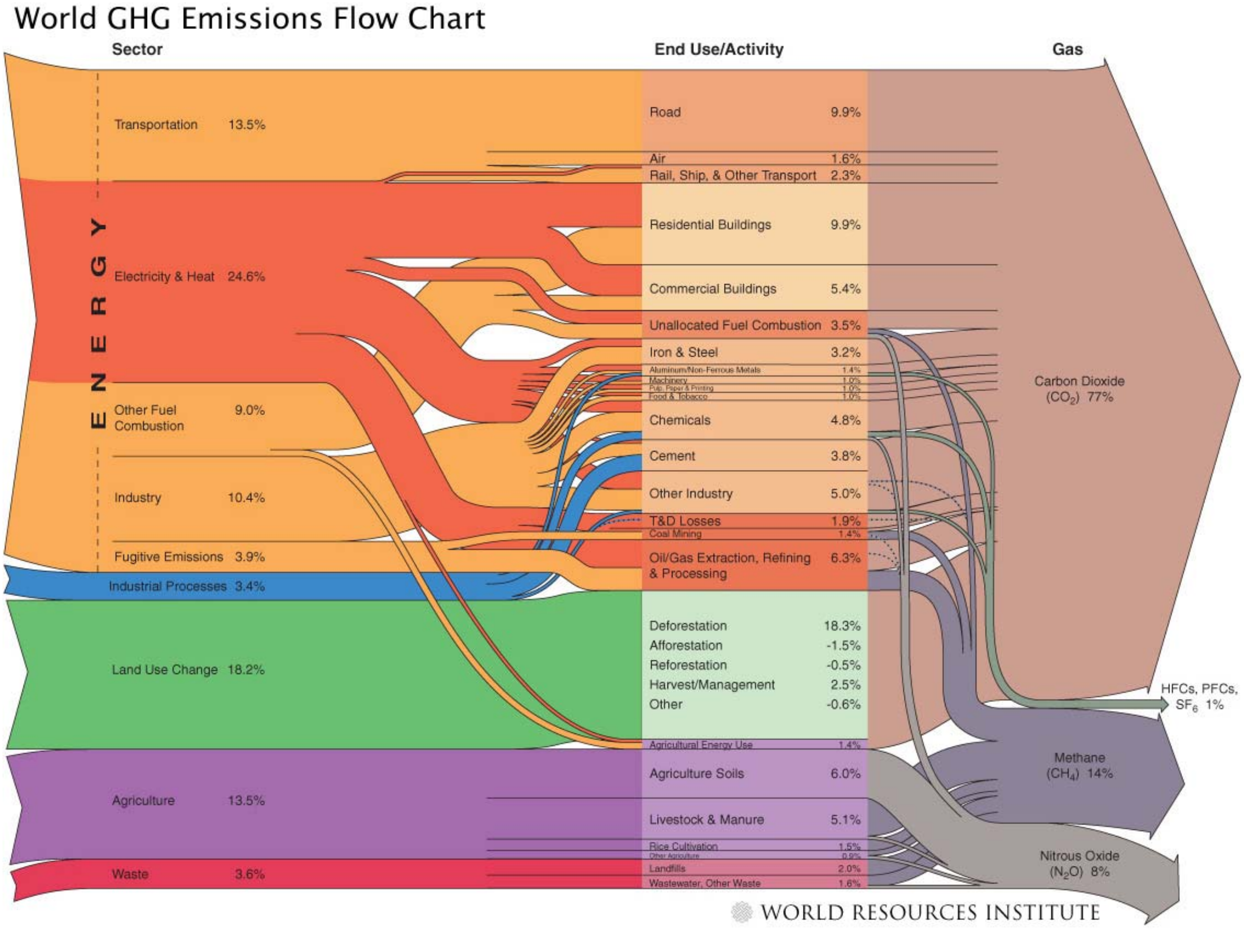
1. INTRODUCTION

In the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), Smith et al. (2007) point out that “agriculture accounted for an estimated emission of 5.1 to 6.1 GtCO$_2$-eqivalent/year in 2005” and was therefore responsible for 10-12% of the total global anthropogenic greenhouse-gas emissions. The World Resources Institute (WRI) estimates agriculture’s contribution to the world’s greenhouse-gas emissions in the years 2000 and 2005 with 13,5% and 13,8% even higher.



Source: Climate Analysis Indicators Tool (CAIT UNFCCC) Version 4.0. (Washington, DC: World Resources Institute, 2011).

Figure 1 ***World greenhouse gas emissions in 2000***

The WRI’s data on agricultural emissions in the year 2000 (see figure 1) was also used by Stern (2006) in his much-noticed review on the economics of climate change. In his review, Stern in some sense criticizes the extent to which agriculture is made responsible for the emission of greenhouse gases: Stern questions, that – following the IPCC guidelines for the preparation of the national greenhouse-gas inventory reports (NIR) – for agriculture solely non-CO_2 emissions of methane (CH_4) and nitrous oxide (N_2O)[1]are reported, while from his point of view agriculture is indirectly also responsible for part of the emissions from the industry and transport sector (production of fertilizer and movement of goods) as well as for CO_2 emissions from the land-use, land-use change and forestry sector (LULUCF). The latter aspect he explains by two arguments. Firstly, he mentions that agriculture could be addressed as the primary driver of world-wide deforestation and the accompanied emissions of CO_2. Secondly, he states that agriculture itself causes CO_2-emissions by applying agricultural management practices which disturb natural carbon sinks and release stores of CO_2 from the soils. In Stern's opinion such emissions could definitely be significant. Nevertheless he points out, that up to now there is no possibility of assessing robust estimates on them – at least not on a global scale – and, that these emissions are not associated with agriculture as they are reported under the LULUCF sector (Stern, 2006).

Calling Sterns hypothesis into question, it seems apparent that in regions, where massive deforestation takes place - such as Tropical Asia, Tropical Africa and Tropical America – CO_2emissions, originating from agricultural soil management, could appear marginal compared to the emissions from deforestation. Also, up to now most of the world's main emitters, namely the United States of America, the European Union as a whole, as well as the Russian federation, report negative emissions from the land use, land-use change and forestry sector (CAIT-UNFCCC, 2011). Significant, soil-prone emissions are apparently not reported or – as deforestation does not take place or is outnumbered by re- and afforestation – are balanced by the forests' function as carbon sinks. However, with his argument, Stern (2006) addresses a topic, which can be eminently important if one does not consider an international or global but a national level. Looking at the single countries of the European Union, it becomes obvious that of all of Europe's main-emitters[2], only one country reports positive emissions from the LULUCF sector, namely Europe's number 1 emitter Germany. The reason for this becomes evident by analysing the LULUCF chapter in line with the German NIR in more detail. Like for the other main emitters in Europe, German forests represent a sink of greenhouse gases. However, these savings are completely outnumbered by extremely high CO_2-emissions from agriculturally used crop- and grassland. Balanced by other emissions and savings from wetlands, biomass, etc., Germany's LULUCF sector closes with a positive balance of about 17.560 Gg CO_2equivalent (NIR, 2011). Naturally the question arises, why Germany shows such high emissions from agriculturally used crop- and especially grassland, which normally functions as a sink of greenhouse gases.

Table 1 depicts the reason: responsible for the high emissions in the German LULUCF sector is the agricultural use of peatlands. This land use causes 87% of the cropland-emissions; as regards grassland, 13.204 Gg CO_2 result from organic peatland soils.

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[1] from fertilizer use, livestock and other sources like rice and manure management

[2] Germany, United Kingdom, Italy ,France, Spain and Poland

Table 1: Emissions from Germany's LULUCF sector in Gg CO_2 equivalent (NIR 2011)

forests	-25.421,59
cropland on drained peatlands	23.482,00
cropland mineral soil	2.530,00
cropland biomass	-591,85
liming	1.682,96
grassland on drained peatlands	13.204,91
grassland mineral soil	-1.603,44
grassland biomass	-880,62
wetlands	2.408,29
settlements	2.278,57
other	65,42
from N2O from forest and cropland	403,27
from CH4 from forest	4,62
∑	17.562,54

The high emissions from the cultivation of peatland sites are the result of the functional principle of these ecosystems and the current land use, which in Germany on the one hand takes place on nearly all peatland sites and which, on the other hand, is characterized by a comparably high intensity (Hirschfeld et al., 2008). Under natural conditions peatlands continuously take up CO_2, which then is stored as carbon in the system – 1 as under flooded conditions decomposition is suppressed by the absence of oxygen. By draining and agricultural cultivation the process of decomposition commences. Large fluxes of greenhouse gases going back into the atmosphere are the consequence. However, as current research shows, aerobic mineralization as well as carbon losses can be limited or even stopped by reducing agricultural intensity and restoring the sites via rewetting (Limpens et al., 2008; Freibauer et al., 2004).

Against this background it becomes clear, that - taking account of the reported data of the NIR 2011 – nearly 4% of Germany's emissions could be cut by introducing agricultural changes on these peatland sites. Especially in line with policy's seek for new ways to meet emission-reduction targets, which also take agricultural production more and more to task, such measures appear likely to be taken into consideration. As pointed out earlier, emissions from the LULUCF sector are not associated with agriculture. Up to now, recommendations for agricultural emission-mitigation strategies mainly focus on the reduction of the reported gases N_2O and CH_4 (e.g. decrease of numbers of animals, shift to organic farming, decrease of fertilizer use, etc. (McKinsey, 2007)). However, in the fourth assessment report of the IPCC, Smith et al. (2007) (p 509) already specify, that a very prominent option for GHG mitigation in agriculture is the restoration of degraded lands and the restoration of organic soils which are drained for crop production.

Our study takes the German emissions from peatland management as an example to analyse, how agricultural land-use changes can contribute to emission reduction in the LULUCF sector. We strongly focus on the question, whether this option of GHG mitigation is a cost-efficient measure which is to be recommended for implementation. To assess the economic competitiveness of emission-mitigating land-use strategies in the LULUCF sector, we build an economic model to calculate CO_2 abatement costs of changes of agricultural management practices which directly influence CO_2 emissions from agricultural used soils. With the calculation of CO_2 abatement cost, we choose an instrument which is widely applied and highly accepted by various economists who have been rating the cost-efficiency of strategies of climate protection (e.g. McKinsey, 2009; Bloomberg, 2010). The use of abatement costs enables the comparison and ranking of extremely heterogeneous and almost incomparable measures of climate protection (Matthes, 1998; Beer et al, 2008; Sterner, 2003).

We conduct our analysis in six German peatland regions. However, this paper focuses on the results of two selected regions which are presented in Chapter 2. The natural-scientific data on land-use specific emissions, which allow for the identification of recommendable management changes, originate from own measurements in the study regions. Also microeconomic data was collected in the study regions by carrying out comprehensive farm surveys. Using this database we derive costs of CO_2 mitigation by calculating income effects of land-use changes and contrasting them with the related reduction in greenhouse-gas emissions. Our database and our method to carry out farm-individual and plot-specific calculations are described in Chapter 3. The results of our study are presented in Chapter 4. Here we show the economic consequences and cost-efficiency of different measures considering the impact of regional conditions. While discussing our results in Chapter 5 we widen our perspective and compare the performance of our study objects with results from non-agricultural fields. A conclusion is drawn in Chapter 6.

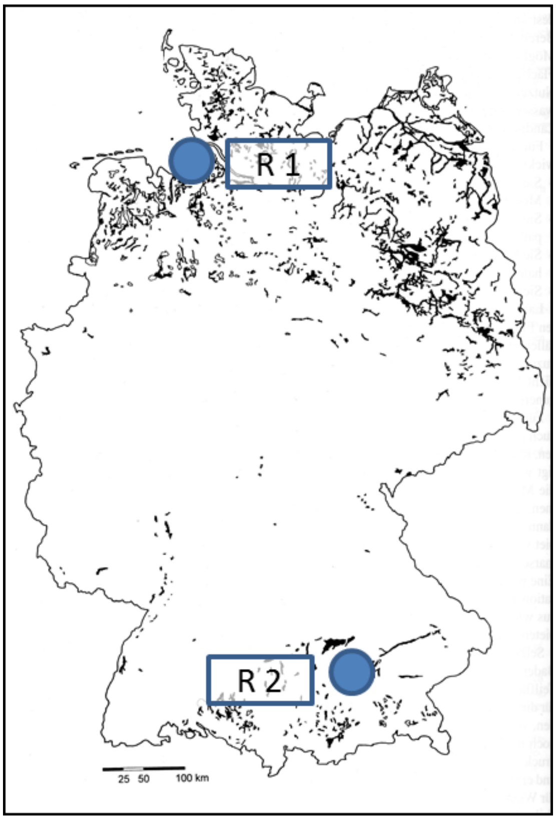

Figure 2: Location of the sample regions

2. REGIONS OF STUDY

The two study regions represent typical natural and agro-economic conditions in the north-west and south of Germany. R1 is a bog site which covers about 4,000 ha. Only about 17 percent of the peatland is uncultivated, of which only 1 to 2 percent can be considered as “close to nature”. Conservation area is located at the edges of the bog. R2 is a fen site fed by a continuous groundwater stream with an extension of about 600 ha. Within the core region, ecologically valuable litter meadows are maintained under conservation programmes. In R1 peatland is exclusively used as intensive grassland focused on forage production. In R2 UAA is used as grassland for forage and biogas-production and as arable land for cash crop, energy-crop and forage production.

3. METHOD AND DATABASE

Our economic model calculates abatement costs of reductions of soil-borne CO_2 emission, which can be reached by changes of agricultural land-use practices. At this, we identify selected CO_2-mitigating land-use strategies and analyse farmers' income forgone resulting from the implementation of such strategies. Consequently, we derive costs per ton CO_2 saving for the chosen land-use strategies by contrasting the calculated income effects of the various land-use strategies with the related reductions in greenhouse-gas emissions.

Identification of CO2-mitigating land-use strategies

To identify potential land-use strategies, which implicate relevant reductions of GHG-emissions, we measure GHG-fluxes of common land-use strategies within six representative German peatland regions. As the outcome of the measurements, Global Warming Potentials (GWP) (measured over the timescale of 100 years) are assigned to the different land-use strategies. Consequently the mitigation potentials of management changes are determined. In peatlands particularly the fluxes of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have to be considered. To derive total GWPs, additionally the import and export of C is included. GWPs are quantified by the unit of carbon dioxide equivalent (CO_2-C equiv.). GWP-factors for CH_4 and N_2O correspond to the internationally accepted quantification of the Second Assessment Report (SAR) of the International Panel of Climate Change[3] (IPCC, 1995). The GWP balance (gas-exchange) of the land-use types (LU) is calculated as:

$$GWP_{LU} \text{ (in } CO_2\text{-C equiv.)} = CO_2\text{-C } bal_{LU} + CH_4\text{-C } bal_{LU} * 7.6 + N_2O\text{-N } bal_{LU} * 133 + (C\text{-}Import_{LU} - C\text{-}Export_{LU})$$

Mitigation potentials emerging from land-use changes are derived by comparing the specific GWPs of the single land-use types to each other. Again, the amount of reduction (R) can be expressed by CO_2-equivalencies.

$$R_{LU1 \rightarrow LU2} \text{ (in CO2-C equiv.)} = GWP_{LU1} - GWP_{LU2}$$

Analysing the extent of mitigation achievable due to shifts between land-use types, a cascade recommending relevant climate-effective land-use conversions was developed.

Analysis of farmers' income forgone

The economic database used for calculating farmers' income forgone was collected in comprehensive regional farm surveys. To analyse the economic effects of emission-mitigating management strategies, the status quo of agricultural valued added on the sites is modelled. For this, we analyse the current regional organisation (type of farming) of the farms and their individual land use. Based on this analysis, we carry out farm-individual and plot-specific calculations of gross margin. By analysing potential changes of gross margin – as resulting from management changes – we derive losses of income.

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[3] According to SAR, CH_4-C holds a multiplication factor of 7.6, N_2O-N of 133.

Regional farm organisation/type of farming:
The surveyed farms were classified according to standard gross margin (SGM) following the European Commission Decision of 16 May 2003 amending Decision 85/377/EEC (EU, 2003). The classes we chose correspond to the typology of the surveyed farms. It was possible to organise all of the surveyed farms within the classes of "Specialist field crops", "Specialist granivores" (divided into "Specialist pigs", and "Specialist poultry"), "Specialist grazing livestock", (divided into "Specialist dairying", "Cattle fattening", "Suckler cows"), "Mixed livestock", "Mixed livestock/field crops" and "Non classifiable". For the classification of the surveyed farms, regional standard gross margin was calculated using SGM values provided by "The Association for Technology and Structures in Agriculture" (KTBL, 2010). For market crops the five year average (2003/04 – 2007/08), and for animal production the three year average (2005/06 – 2007/08) of SGM values was used.

Regional land use
Corresponding to the variable types of farming, variable types of land use dominate within the regions. To analyse land-use specific agricultural value-added, every site recorded in the farm survey was scrutinised individually. In total, 757 peatland and non-peatland sites were examined. Of the 417 cropland and 340 grassland sites, respectively 120 and 233 sites were situated on peatland. Type of land use on the sites was differentiated into ***cropland*** for a) market- and b) forage[4]-crop production and ***grassland*** for a) forage[1] production or b) with no or low agricultural use (litter-meadows/uncultivated grassland). Grassland used for forage production was further divided into the land-use types *meadows* (exclusively cut), *meadow/pasture* (combination of cut and pasture) and *pasture* (exclusively pasture). As regards grassland productivity, yields were estimated individually for each site by analysing the farmers' statements about yields (quantity, quality, type of product) as well as on their specifications on cut frequency, type of fertilisation (inorganic, organic), intensity of fertilisation, stocking rate and duration of pasture. Farmers' information about the sites was individually validity-checked by reconciling statements with empirical and statistical data (official harvest statistics, interviews with expert). Productivity was quantified by assigning yields of fresh mass (equivalent to the yields of 1- to 5-cut meadows) to each site. On the basis of productivity levels, grassland was ranked within three levels of intensity, namely „low", "moderate" and "high". As regards quantification of intensity levels, "low" was assigned to 1- and 2-, „moderate" to 2,5- and 3- and „high" to 3,5 to 5-cut productivities. Subsequent to this "site-by-site" classification, the assigned site-specific levels were cross-compared within the single regions as well as across the different regions. In case of inconsistencies, productivity and intensity were re-checked and adapted if necessary. Thus, we ensured comparability and appropriate ranking of productivity. Figure 2 gives an overview of the chosen classification of land-use types.

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[4] In line with this study the term "forage" is consistently used to describe forage used as basic ration such as maize silage or grassland products such as green forage, grass-silage, hay. Marketable forage crops used as concentrate such as wheat, barley, corn, etc. are considered as market crops.

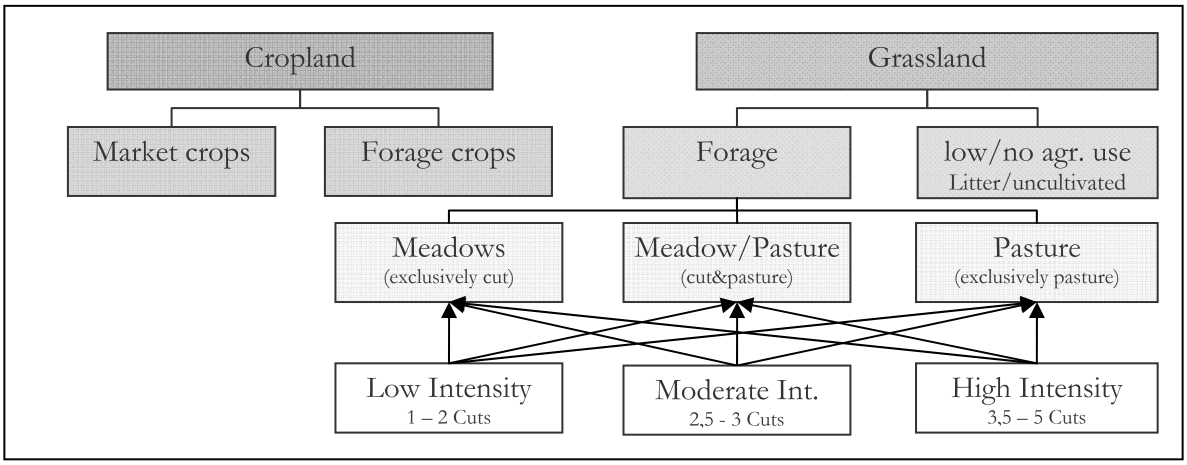

Figure 3: Classification of land-use types

Farm-individual and plot-specific calculations of changes in gross margin and processing value

To calculate the microeconomic costs of changes of land-use practices we analysed annual agricultural income forgone resulting from a change of value added on the sites. We carried out farm-individual and plot-specific calculations of "gross margin" for market-crop production and "processing value" for forage production. Gross margin is defined as the difference between value of output and variable costs of a produced item. It remains as contribution to profit and to cover remaining (fix-) costs. By calculating management-related changes of gross margin or processing value, we fulfil the requirement to determine annual monetary values which correspond to an annual saving of CO_2 emissions from the soils (Dabbert, 2006).

Gross margin of ***cropland for the production of market crops*** (GM_{MC}) is calculated by multiplying amount of crop output per hectare[5] with the regional market-price ("value of output") and subtracting the cost of variable inputs[6] required to produce the output. Calculation is done farm-individually taking into consideration of the farms' specific production process, as well as with regard to regional producer-prices and costs (Reisch & Zeddies, 1977).

$GM_{MC} = [(\text{Output Items in kg/ha}) * (\text{Market Price in €/kg})] – (\text{Cost of Variable Inputs in €/ha})$

Direct designation of gross margin of ***area used for forage production*** (forage crops and grassland for forage production[7]) is not possible as long as the produced forage is not put on the market but used in the farms' animal-production process. Therefore, for forage area "processing values" (PC) are calculated (Reisch & Zeddies, 1977; Althoetmar, 1964). PC-Values are used as equivalent to "value of output" of market crops. For the derivation of PC-Values, gross margin of roughage-consuming husbandry types (dairy cattle, cattle fattening, suckler cows) is calculated (GM_{HT}) without costs for farm-produced forage. Divided by forage-nutrient-claims (NC) necessary to produce GM_{HT}, the PC-Value per nutrient-unit (PC_{NU}) is derived.

Generally PC_{NU} can be described by the equation:

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[5] Output in kg/ha: eg. kg/ha corn, wheat, barley, oats, rye, triticale, rapeseed, etc.

[6] Incl. costs of seed, fertilisers, plant protection, machine costs, harvest, fertilisation, insurance, drying, processing.

[7] In line with this study the term "forage" is consistently used to describe basic ration such as maize silage or grassland products such as green forage, grass-silage, hay. Marketable forage crops used as concentrate such as wheat, barley, corn, etc. are considered as market crops and valued by their market price as they could be sold and bought on the market.

$$PC_{NU} = \frac{GM_{HT}}{NC_{HT}}$$

To derive farm-individual and plot-specific PC_{NU}s, we created "weighted PC_{NU}s" for the forage-land-use types (LU) "silage maize", "cut grassland" (meadows and meadow/pasture) and "pasture".

Farm-individually we analysed coverage of forage nutrient claims (NC) for all types of animal husbandries realised, considering farm-individual forage diet composition. Consequently we derived nutrient-claims (NC) for the total stock of one husbandry type (HT).

$$NC(AU_i) = N_{SM(AU_i)} + N_{CG(AU_i)} + N_{P(AU_i)} \quad (1)$$

$$NC(HT_i) = \left(\sum AU_i\right) * NC(AU_i) \quad (2)$$

i = Husbandry type eg. dairy, cattle-fattening, AUi = Animal Unit of one husbandry type, N= Nutrients in forage diet, N_{SM} = N from SilageMaize, N_{CG}=N from cut grassland, N_{P}=Nutrients from pasture

We identified the amount of nutrients which the total stock of one husbandry type demands from one individual land-use type (3). Consequently we derived the total amount of forage-nutrients demanded by all HTs from one land-use type (4).

$$NC(HT_i)_j = \left(\sum AU_i\right) * N_{j(AU_i)} \quad (3)$$

$$NC(TD)_j = \sum_{i=1}^{n} [NC(HT_i)_j] \quad (4)$$

TD = Total demand, n = Number of different husbandry types eg. dairy, cattle fattening…, j = Land-use type (silage Maize (SM), cut grassland (CG), Pasture (P)

Furthermore, we determined the share (S) of the single husbandry types in total demand from one land-use type (5) and derived how much the single GM_{HTi}s[8] (6) contribute to the overall PC_{NU} of one land-use type [PC_{NU} (LU)] (7).

$$S(HT_i)_j = \frac{NC(HT_i)_j}{NC(TD)_j} \quad (5)$$

$$GM(HT_i) = \left(\sum AU_i\right) * GM_{(AU_i)} \quad (6)$$

$$PC_{NU}(LU_j) = \sum_{i=1}^{n} \left[S(HT_i)_j * \left(\frac{GM(HT_i)_j}{NC(TD)_j} \right) \right] \quad (7)$$

The total processing value per hectare forage area was calculated by multiplying the sites' individual production of nutrient units per hectare with their individual, weighted PC_{NU}. Production of nutrient-units per hectare (NU_{ha}) was determined on the basis of the assigned level of productivity (as described earlier) and under consideration of the farms individual production

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[8] GM_{HT}s are calculated farm-individually taking into account the surveyed farms' individual production process and output (eg. milk yield, composition of diet, fattening period, etc.) as well as with regard to regional market prices and costs.

processes per ha ($C_{ha}(LU)$). Subtracting the farms' individual costs of variable input[9] to produce NU_{ha} we determined a value for "GM_{HT}-derived Forage-PC" (PC_{GMHT}) (8) per ha which is comparable to gross margin of crop production (GM_{MC}).

$$PC_{GMHT}(LU_j) = (NU_{ha}(LU_j) * PC_{NU}(LU_j)) - C_{ha}(LU_j) \quad (8)$$

GM_{MC} and PC_{GMHT} represent the basic values to calculate plot-specific income forgone due to management changes. Income forgone per ha hereby constitutes the difference between GM_{MC} resp. PC_{GMHT} created prior to management changes and GM_{MC} resp. PC_{GMHT} producible after the conversion of land use. Income forgone (ha) (IF_{ha}) is therefore defined as (9):

$$IF_{ha}(LU) = VA_{LU}(t=0) - VA_{LU}(t=1) \quad (9)$$

VA = Value added expressed by GM_{MC} resp. PC_{GMHT}, t(ime) : t=0 :Status quo, t = 1: after implementation

Generally, the higher GM_{MC} resp. PC_{GMHT} in the status-quo situation, the more drastic are the income effects after changing management. Basically, for forage area it can be expected that the more intensive the land use, the higher, respectively the less intensive the land use, the lower are site-productivity and forage-quality and therefore total PC_{GMHT} per ha.

Farm individual and plot-specific costs per ton CO_2-equivalent

In order to compare the cost-efficiency of the achievable emission reduction we calculated costs of GWP reduction for the chosen land-use strategies. For this, we contrasted the calculated income forgone with the related reduction in greenhouse-gas emissions (in t CO_2-C equiv. $ha^{-1}a^{-1}$), which was derived from the site-specific measurements of greenhouse gas in the study regions..

The calculation of plot-specific costs follows the equation:

$$Costs / tCO_2 equiv.^{-ha*a} = \frac{IF_{ha}(LU)}{\text{t CO}_2 \text{ - C equiv.}^{-ha*a}} \quad (10)$$

4. RESULTS

The results of our study show that costs of CO_2 mitigation vary according to different levels of land-use reorganisation. Variety results, on the one hand, from the amount of GHG mitigation achievable and, on the other, from the amount of agricultural income forgone. With respect to CO_2 emissions, our results show that the intensity of agricultural land use and the level of groundwater tables are the main factors which influence GHG emissions. The water table in particular dominates the exchange of CO_2, N_2O and CH_4 within the ecosystem: peat profiles which hold water tables close to the surface are characterised by anaerobic conditions below the mean water table, while aerobic conditions are limited to a shallow upper layer. If the water table drops down (eg. through drought or drainage), the aerobic zone in the profile extends, resulting in rising soil respiration and mineralisation. The degradation of the carbon [C] and nitrogen [N] stocks in the peat transforms the peatland from a strong C and N sink to a potentially very strong C and N source in terms of CO_2 and N_2O emissions. Even if emissions of CH_4 are usually discontinued or

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[9] Farm individual costs of seed, fertilisation, plant protection, machine costs, harvest, fertilisation, insurance, drying, processing

are even changed to small CH_4 uptake after draining, this effect is outweighed by the pronounced increases in the other two gases. Therefore the thickness of the upper aerobic zone is of major importance for the gas fluxes. Land-use types necessitating the lowest water tables, namely arable land and high-intensive grassland, are accompanied by the highest GWPs. As regards climate footprint, arable land and intensive grassland are almost comparable: the difference in GWP stands at a maximum of about 5 to 10 t CO_2-C equiv. $ha^{-1}a^{-1}$. Significantly lower GWPs occur on grassland sites which hold higher water tables and are either managed with low agricultural intensity (1 to 2 cuts, low fertilisation, low stocking rate) or kept under maintenance. Here GWPs stand at about 50 % below the GWPs of intensive land-use types. Quasi zero emission occurs on sites which have been restored by withdrawing any land use and enhancing the water table to an annual average of about 10cm below ground surface. These results apply to bogs as well as to fen sites, while generally emissions on fen sites exceed emissions on bog sites. With regard to recommendations of land-use changes which imply the highest mitigation potentials, the results reveal three major "mitigation steps", as shown in Table 2. First of all, even if mitigation potentials are limited, arable land use should be abandoned and changed into grassland use, as aeration resulting from ploughing strongly accelerates soil degradation. Secondly, implying high mitigation potential, arable land as well as intensive grassland should be changed into grassland with low-intensive agricultural management respectively into grassland maintained under nature conservation programmes. Thirdly, as the most drastic though the most climate-effective step, a change from arable- respectively intensive grassland to complete and adapted restoration is recommended - resulting in complete abandonment of agriculture.

Table 2: Recommended land-use changes implying relevant GHG mitigation potentials

	Initial land use	**Target land use**	**GWP Mitigation Potential**
(I)	Arable land	Grassland (Intensity high or medium)	+
(II) (a) (b)	Arable land / High intensive grassland	Low intensive grassland [(a) agric. use: 1 to 2 cuts or low intensive grazing; (b) maintenance]	++
(III)	Arable land / High intensive grassland	Restoration (Abandonment of land use, average annual water table at 10cm below surface)	+++

These results show, that the intensity of agricultural land use must be clearly decreased in order to achieve reasonable reductions. Naturally, such a step requires significant changes in agricultural management and is presumably accompanied by severe consequences for the micro-economic situation of farms. When comparing our two study regions, it becomes clear that regional basic production conditions, management strategies and consequently the severity of consequences as regards associated agricultural costs and farmers' income forgone vary significantly. For our study regions, substantial differences concerning farm organisation, type of farming and peatland use are observable (see Table 3). Region 1 represents a pronounced dairy-cattle region with highest levels of milk performance (average milk yield at 9000 litres). All farms involved in the farm survey are run as conventional, commercial farms. The region is characterised by a high share of peatland area per farm (89% on average), which is mainly managed as high-intensive grassland for forage production. In contrast, Region 2 shows broad variability as regards farm organisation as well as in peatland management. Besides "traditional" dairy-cattle farming, to almost the same percentage farms specialise in market-crop production or generate their agricultural income by a mixture of animal husbandry and cash-crop production. A considerable number of farmers (11% "non classifiable", see Table 2) practise niche productions such as willow cultivation or herb and grass breeding. As regards peatland use, R2 is characterised by a comparatively low share of area per farm (36% on average). A remarkable share of this peatland area (37%) is managed as arable land for cash-crop and forage production. Considering grassland management within R2, intensity is significantly lower than in R1, whereas the percentage among low, medium and high intensive grassland is nearly equal.

Table 3: Portrait of the study regions

Farm organisation, type of farming (in percent)	**R1**	**R2**
Commercial farms:	100	95
Organic farms:	-	26
Specialist field crops:	-	26
Specialist granivores:	-	5
Specialist dairying:	100	32
Cattle fattening:	-	5
Mixed livestock/field crops:	-	21
Non classifiable:	-	11
Peatland use (Percentage of peatland total):		
Arable forage	1,5	17
Arable cash crops	-	20
Grassland intensity high	73	20
Grassland intensity moderate	20	21
Grassland intensity low	5,5	20
Litter meadow	-	2
Average farms' peatland area (%)[1]	89	36

1) Share of peatland in the interviewed farms' total UAA.

Along with the differences in back-grounding type of farming as well as in type and intensity of land use, total processing values per hectare forage area (PC_{GMHT}) and gross margins of sites used for market-crop production (GM_{MC}) vary significantly. Table 4 shows average PC_{GMHT}s and GM_{MC}s of the two regions' forage- and cash-crop land-use types. Comparing the regions as regards PC_{GMHT}s, we see that processing values in R1 clearly exceed Processing values on sites in R2. The primary causes are the different types and different intensity levels of animal husbandry. In R1, exclusively $PC_{(NU)}$-values derived from gross margins of dairy-cattle husbandry determine PC_{GMHT}. The extremely high level of milk performance (9000 l on average), creating high gross margins per dairy cattle, combined with the high level of land-use intensity, allowing for feeding more than one dairy cattle per hectare, lead to the extremely high processing values on forage sites. An outstanding performer in this respect is arable land used for silage maize production - due to the high amount of nutrient units producible per hectare. Also moderate- and low-intensively used grassland within R1 creates remarkably higher PC_{GMHT}s than in R2, as even low-quality grassland products are processed by dairy husbandry, namely as forage for breed. Generally, within R2, $PC_{(NU)}$ values are driven by animal husbandry such as cattle fattening, suckler cows and dairy cattle, with an average milk performance of 6400 l. Consequently, PCs per nutrient unit are lower in R2, as being derived from animal husbandries creating lower gross margin. Especially on sites producing less nutrient units per hectare, the difference becomes significant.

Table 4: Average[1] PC_{GMHT} and GM_{MC} of forage- and cash-crop land-use types (€ per hectare[2])

	R1	R2
Cash crops		
Total cash crops [3]:	-	464
Forage production		
Silage maize:	3877	2868
Grassland intensity high:	1894	1526
Grassland intensity moderate:	1706	851
Grassland intensity low: (agricultural utilisation)	867	479
Grassland intensity low: (maintenance) [4]	182	158

[1] weighted by amount of area

[2] Area payment included (federal target values 2013)

[3] Investigated cash-crops include winter wheat, winter barley, summer barley, winter rye, corn and oat.

[4] Considered are machine costs, costs of harvest, product utilisation (eg, composting or marketing of litter or hay)

As regards cash crop production, our results show certain variety of gross margin here as well, even if the range of variety is much narrower than it turns out to be on forage sites. Depending on the type of market crop cultivated, gross margins vary between about 410 and 690 Euro per hectare (without taking into account marketable crops which create negative gross margin and are mainly cultivated for the needs of crop rotation). When finally comparing all values of land-use types, a notable fact is that gross margin of cash crop lies far below processing values of forage area. However, bearing in mind the definition of gross margin as being the contribution to profit and to cover remaining fixed costs, this phenomenon is justified. The high gross margins of animal production which drive PC_{GMHT} can still be compared to gross margin of cash crops when being converted to the coverage of fixed costs and the payment of working hours.

Going hand in hand with the different "status-quo" income levels for different types of peatland use, is the variation of the amount of income forgone for different levels of management changes. Table 5 presents the results of our study as regards agricultural income forgone associated with the implementation of the three potential steps recommended to mitigate GHG emissions. Furthermore, the table shows income forgone per t CO_2-C equivalent derived by contrasting costs of implementation with the respective savings of CO_2 equivalents. When looking at the numbers, we see that in R1 almost continuously the costs per ton CO_2-saving are higher than in R2. They range between €60 and €370 for those land-use changes with given mitigation potentials. (In the case of a conversion of silage maize area into intensive grassland in R1– implying no CO_2-mitigation potential on bog sites – the costs equal the sum of income forgone and therefore stand at about € 2000 per hectare.) In R1 the combination of two factors is responsible for pushing costs up. On the one hand we certainly have the high "status quo" of agricultural value added – resulting in high losses of agricultural income if the management is changed. On the other hand, we have the natural conditions of a bog site. As indicated earlier, GHG emissions - and therefore also GHG mitigation achievable via land-use changes - are lower on bog than on fen sites. In R1, mitigation potentials lie within a maximum mitigation range of 0 t CO_2-C equiv. $ha^{-1}a^{-1}$ for the change from arable land to intensive grassland and about 30 t CO_2-C equiv. $ha^{-1}a^{-1}$ for the change of arable land into complete restoration. Consequently in R1 the high economic costs are balanced by lower emission reductions compared to R2. In R2, costs vary between a range of minus €100 up to €270 per t CO_2-C equivalent. The reason for these considerably lower costs is the lower $PC_{(NU)}$ derived from lower-intensive animal husbandry and the natural site conditions. As being a fen area, mitigation potentials are significantly higher than in R1 and vary between around 10 and 40 tons CO_2-C equiv. $ha^{-1}a^{-1}$. Consequently, even if costs of implementation are high - for example, management changes from silage-maize production to low-intensive grassland kept under maintenance – costs turn out to be comparatively low related to the mitigation of one ton CO_2-C equivalent. If we look at abatement costs of cash-crop production, it even appears to be a win-win-situation for climate as well as for farmers if production were abandoned and the area was changed into forage-land for animal production. Per se this statement and the economic calculation are correct, yet it is clear that for example "specialist field crop" farms do not have the opportunity to process grassland products via animal husbandry. Therefore the "negative costs" occurring for a change of cash-crop area into intensive grassland can only be justified for farms which already keep animals and can utilise the additional forage products – either in their current production process or by increasing animal production within existing capacity.

Table 5: Income forgone of recommended management changes (€/t CO_2-C equiv.)

Land-use change	**Initial Use**	**R1**		**R2**	
		Agr. income forgone	**Cost/t CO_2 – equiv.**	**Agr. income forgone**	**Cost/t CO_2 – equiv.**
(I) Arable to GL high	Cashcrop	-	-	- 1062	-106
	Silagemaize	1983	1983	1342	268
(II) (a) Arable/GL High to GL low agr.	Cashcrop	-	-	- 15	-1
	Silagemaize	3010	368	2389	128
	GLhigh	1027	126	1047	69
(II) (b) Arable/GL High to GL low main.	Cashcrop	-	-	306	9
	Silagemaize	3695	130	2710	83
	GLhigh	1712	60	1241	48
(III) Arable/GL High to restoration	Cashcrop	-	-	464	11 *
	Silagemaize	3877	134 *	2868	70 *
	GLhigh	1894	65 *	1526	41 *

* Taken into account is direct payment forgone in the case of abandonment of agricultural area

To summarise briefly the results of our analysis, one sees that especially within regions where value added on peatland sites is high while mitigation potentials are comparatively low, income forgone per ton CO_2 mitigation can turn out to be extremely high. Correspondingly, within regions which hold high mitigation potentials, changes of peatland management can be a cost-efficient strategy to mitigate GHG emissions in the LULUCF sector- even if economic costs appear to be high at first.

5. DISCUSSION

Our results show that CO_2emissions in the LULUCF sector of single countries can be significantly decreased by applying specific changes of agricultural land-use practices. The calculation of abatement costs of promising mitigation measures – via contrasting income forgone with emission-reductions achievable – gives hints for identifying the most cost-efficient changes of management-strategies. However, there are different points which must be considered when interpreting our results. By choosing gross margin and processing value to derive agricultural income forgone, we made the clear decision to look at short-term costs. In this respect, the results show site-specific costs which would occur in the concrete moment of an implementation of land-use changes – for farms which are in a status-quo situation of farm organisation, type of farming and land-use strategy. In contrast to a long-term consideration, possible adaptation strategies (eg. changes in farm organisation or shifts of production to alternative areas) are not considered. Furthermore, the use of gross margin and processing value represents “the ceiling” of valuing agricultural area. Agricultural area could also be associated with lower values such as the market price of forage (if it exists) or the regional rent paid for adequate area. However, keeping these possibilities in mind and comparing them to the values we derive, we can certainly cover the range within which the price per ton reduction of CO_2equivalent will lie. Furthermore, it should be noted that even forage prices and land rents cannot be considered as statically low values. In particular, if large-scale management changes should be implemented, even those values are likely to increase considerably – for reasons of scarcity of land and the increasing demand on the forage market.

With respect to the cost and benefit positions we investigate, it is obvious that they do not cover the variety of positions associated with land-use changes targeting climate protection. We have only considered the farmers’ agricultural income forgone and benefits from emission mitigation. Additional costs and benefits, such as costs of technical implementation and water supply, increases or decreases in biodiversity, macro-economic follow-up costs like damage to buildings or infrastructure or effects on regional development or tourism, are not considered yet and can be significant.

Another area to draw attention to would be the system boundaries within which our study is conducted. At the moment we calculate farm-individual costs which specifically occur on agricultural sites within a peatland area. By doing so, the effects of management changes which emerge beyond these system boundaries are not considered. As already indicated, production limitations on peatland sites can cause production-“exports” or an intensification of production on alternative area. Naturally such adaptation measures can also show negative climate effects: intensification on alternative area can lead to emissions in the energy and transport sector (eg.

intensified fertilisation, enhanced transport); furthermore, new emissions in the LULUCF sector can occur if a possible shift of production causes the creation of alternative UAA, for example via deforestation in other countries. Therefore, for the derivation of macroeconomic and even global cost-benefit relations of CO_2 mitigating land-use strategies, profound scenarios involving effects within much broader system-boundaries have to be analysed.

Finally, looking at our results, it should be noted that the time courses of emission-reduction measurements are still short; therefore also the derived emission factors have to be treated with caution. In order to fill these methodical gaps, future research is planned. In particular, additional positions of costs and benefits will be analysed and the co-operation with research groups measuring greenhouse-gas emission will be strengthened.

Nevertheless, our results show that, as regards land-use management, regional basic conditions influence the costs of CO_2 mitigation. On the one hand current value added, on the other hand natural mitigation potentials drive the cost-efficiency of management strategies. When comparing our study regions R1 and R2, we were able to see that land-use changes go along with different amounts of agricultural income forgone. Depending on CO_2 savings which balance income forgone, costs per ton CO_2 equivalent turned out to be either comparatively high or low. Analysing the socio-economic status-quo situation in the regions, we can go so far as to estimate in which kind of regions emission-mitigating land-use strategies appear to be more cost-efficient or expensive. Particularly in regions where area is managed with high intensity, involving high-grade and capital-intensive animal husbandry, management changes are likely to turn out costly. Furthermore, if management strategy is strongly determined by site conditions (eg. pronounced grassland sites) and the share of affected area is high, farmers' flexibility with regard to adapting is limited and management changes will presumably be refused. In contrast, an implementation of management changes in regions which are already characterised by low-intensive agriculture appears to be more promising. Especially if accompanied by low shares of affected area and high mitigation potentials, land-use changes might be a competitive way of reducing CO_2emissions from the LULUCF sector. Generally, (again being aware of the limited system boundaries) compared to alternative techniques, the abatement costs we derive still display an acceptable range.

Biomass-strategies in the transport sector for instance cause abatement costs varying from €150 up to €470 per ton (e.g. rapeseed-methyl-ester, biomass to liquid, biodiesel, ethanol, bio-gas)(WBA, 2007). The restructuring of common cars towards low-emission vehicles leads to abatement costs which range between €130 and €150 per ton CO_2 equivalent (McKinsey, 2007). Furthermore, some abatement strategies within the transport sector create abatement costs which make up even more than €1.000 per ton CO_2 equivalent. (Bioethanol from wheat or sugar-beet, hybrid drives (WBA, 2007; McKinsey, 2007). Also within the energy sector, abatement costs often exceed the € 200 mark (e.g. power generation via biomass, photo-voltaic systems) (WBA, 2007; König, 2009, McKinsey, 2007, Rauh, 2009).

Despite this potential competitiveness, as a final note it should be pointed out that in the case of CO2 reductions, benefits appear to be social whereas costs are private. Farmers would have to bear the costs of adaptation and would not directly profit from the emission-mitigating land-use change. Consequently, in order to successfully implement measures to reduce CO_2 emissions from agriculturally used soils, it is necessary to either implement adequate agro-environmental programmes to compensate resulting income losses or to introduce new instruments, which allow for attributing emission reductions in the LULUCF sector directly to the farmers efforts – with the consequence of the payment of a fair price for the achieved reduction of emissions.

6. SUMMARY AND CONCLUSION

Following the IPCC guidelines for the preparation of the National greenhouse-gas Inventory Reports, for agriculture solely non-CO_2 emissions of methane (CH_4) and nitrous oxide (N_2O) are reported. Nevertheless, it seems obvious that agriculture also causes CO_2-emissions by applying agricultural management practices which disturb natural carbon sinks and release stores of CO_2 from the soils. Up to now, these emissions are not associated with agriculture as they are reported under the land use, land-use change and forestry sector (LULUCF) sector. However, for single countries, CO_2 emissions from agriculturally used soils can be eminently important and ways to reduce such emissions by changing agricultural land-use practices are already considered in order to meet emission reduction targets. Using the example of Germany, our study analyses, how agricultural land-use changes can contribute to emission reductions in the LULUCF sector. At this, our study focuses on the question, whether this option of GHG mitigation is cost-efficient and should to be recommended for implementation. To assess the economic competitiveness of emission-mitigating land-use strategies in the LULUCF sector, we build an economic model to calculate CO_2 abatement costs of changes of agricultural management practices which directly influence CO_2 emissions from agricultural used soils. To determine cost-efficiency, we conducted farm-individual and plot-specific calculations of agricultural income forgone resulting from specific land-use changes which are recommended to mitigate GHG emissions. By contrasting income forgone with CO_2-savings associated with the land-use changes, we derive income losses per ton CO_2 equivalent. Our results show that income forgone per ton CO_2 equivalent significantly varies due to the regional variability of agricultural structures and natural mitigation potentials. Generally our results show that particularly within regions, where value added on agricultural area is high while mitigation potentials are low, costs per ton CO_2 mitigation can result in being very high. In contrast, within regions that hold high mitigation potentials, changes of management can be a cost-efficient strategy. Compared to alternative common abatement strategies, the costs we derived (ranging mainly between 50 and 380 €/t CO_2 equiv.) appear competitive. However, our results were created within narrow system boundaries which do not allow for consideration of further relevant macro-economic cost and benefit positions taken to have a significant influence on abatement costs. In order to fill these gaps, future research is planned. In particular, additional positions of costs and benefits must be analysed and the system boundaries have to be widened. During our study it became clear that a re-organisation of land use could provide fundamental benefits for society. However, in the case of CO_2 reductions, benefits appear to be social whereas costs are private. Against this background, the question arises how either social benefits can be monetarised in order to finance climate-friendly cultivation strategies, or which common instruments of agricultural politic can be used to subsidise the farmers' losses.

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