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# Agricultural Costs of Carbon Dioxide Abatement via Land-use Adaptation on organic soils

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## KEYWORDS

CO<sub>2</sub> abatement cost, climate change mitigation strategies, microeconomic consequences, organic soil management

## ABSTRACT

Increasing carbon dioxide emissions and related climate effects require mitigation strategies, thereby also emissions caused by agriculture are brought into the focus of political debate. In particular organic soil cultivation, inducing significant CO<sub>2</sub> emissions is being discussed more and more. This study aims to answer the question of whether changes of organic soil management can serve as cost-efficient mitigation strategies for climate change. To this end we have built an economic model in which farm-individual and plot-specific CO<sub>2</sub>-abatement costs of selected land-use strategies are calculated by contrasting effects on the agricultural income with the related reduction in greenhouse-gas emissions. With respect to microeconomic data we use a dataset collected in six German regions while data on emission-factors originates from co-operations with natural-scientific research groups. Results show that CO<sub>2</sub>-abatement costs vary due to different levels of land-use reorganisation. Reasonable emission reductions are mainly achieved when agricultural intensity is clearly decreased. Agricultural income forgone varies significantly due to production conditions and mitigation strategies. However, even when economic costs are high they may be balanced by high emission reductions and may not result in high abatement costs. Nevertheless, CO<sub>2</sub>-reductions benefits appear to be social and costs private. Agro-environmental programmes must be implemented to compensate resulting income losses.

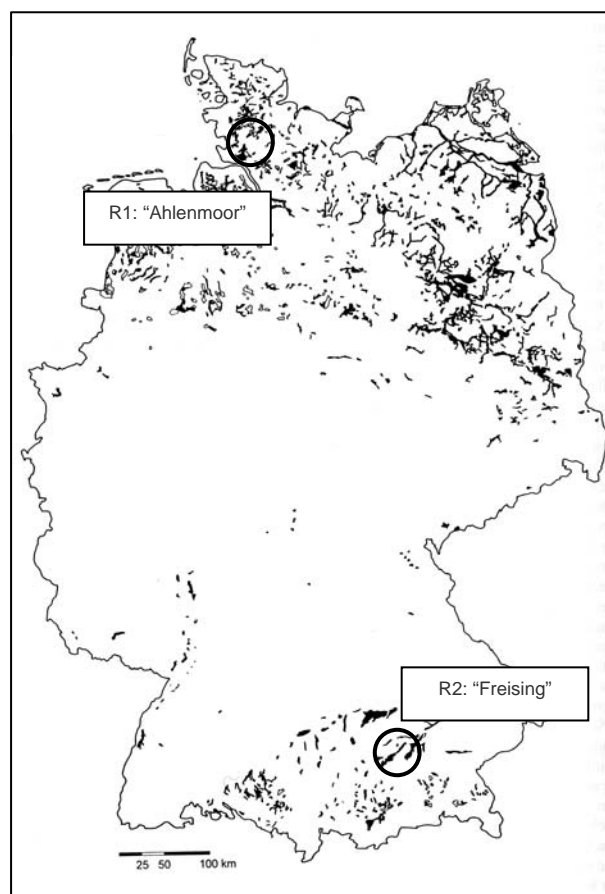
## INTRODUCTION

The increase of carbon dioxide emissions and the resultant effects on the climate are at the heart of the political discussion (cf. UNFCCC, 1998; UN, 2009). Policy begins to establish various measures for emission mitigation and continuously seeks for new ways to meet emission-reduction targets. Since also agricultural production is also a major source of greenhouse gases, naturally the question arises how agriculture can contribute to climate-gas emission abatement. 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<sub>2</sub>-eq/yr in 2005” and was therefore responsible for 10-12% of the total global anthropogenic greenhouse gas (GHG) emissions. The report further specifies that the most prominent options for GHG mitigation in agriculture appear to be improved crop- and grazing-land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management), the restoration of degraded lands and the restoration of organic soils which are drained for crop production.

Our study focuses on the last of these alternatives. Organic soils have accumulated and stored carbon over many centuries, as under flooded conditions decomposition is suppressed by the absence of oxygen (Smith et al, 2007). By draining and cultivating of these ecosystems the process of decomposition commences. Large fluxes of potential greenhouse gases going back into the atmosphere are the consequence - with a significant influence on the climate (Limpens et al., 2008). Byrne et al. (2004) demonstrate that emission factors (fluxes) vary significantly for bogs (nutrient poor, ombrotrophic and oligotrophic peatlands) and fens (nutrient rich, minerotrophic, mesotrophic and eutrophic peatlands) and for different management practices. For intensive grassland sites Global Warming Potentials (GWP) (100yr) were numbered as 2367 for bog and 4794 CO<sub>2</sub>-C Equivalents kg ha<sup>-1</sup>yr<sup>-1</sup> for fen sites. The carbon losses of intensive grassland are even exceeded by the losses observable for arable land use due to enhanced aeration and related mineralization via ploughing. Arable management shows GWPs with 4400 (bog) respectively 5634 (fen) CO<sub>2</sub>-C equiv. kg ha<sup>-1</sup>yr<sup>-1</sup>. In contrast, restoration of the sites via rewetting – dependent on the water level – limits or stops aerobic mineralization as well as carbon losses. Here GWPs make up 192 resp. 736 CO<sub>2</sub>-C equiv. kg ha<sup>-1</sup>yr<sup>-1</sup> for bogs and 559 resp. 179 CO<sub>2</sub>-C equiv. kg ha<sup>-1</sup>yr<sup>-1</sup> for fens. In order to develop more detailed and stable emission factors and management recommendations, the 2006 project “Climate Protection – Strategies of Peatland Management” (Pfadenhauer & Drösler, 2005) measures, monitors and models fluxes of greenhouse-gases of representative land use strategies within representative German peatland areas. In this respect Germany is a particularly interesting “region of study”, as it “turns out as the second-largest emitter (12% of European total) [of GHG from peatlands], although it contains only 3.2% of the European peatlands” (Byrne et al., 2004). In fact, emissions from drained German peatlands currently account for 5,1 % of overall German GHG-emission. Thus drained peatlands in Germany are the largest single source outside the energy sector (NIR, 2010). As regards agriculture, cultivated organic soils make a 30% contribution to overall agricultural emissions while covering only 8 % of the Utilized Agricultural Area (UAA) (cf. Byrne et al. 2004; Hirschfeld et al., 2008). Consequently, by focusing only on the peatlands, agriculture managed significantly to reduce its emissions while

production on only few UAA was affected. However, it has yet to be analysed whether this option of GHG mitigation is a cost-efficient measure which is to be recommended for implementation. A widely applied and highly accepted scientific instrument for rating the cost-efficiency of strategies of climate protection is the calculation of CO<sub>2</sub>-abatement costs. With this instrument extremely heterogeneous and almost incomparable measures of climate protection can be compared and ranked (Matthes, 1998; Beer et al, 2008; Sterner, 2003). In our study we have built an economic model to calculate CO<sub>2</sub> abatement costs of adapted peatland management 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 back-grounding the identification of recommendable management changes originate from close co-operation with natural scientists. The microeconomic data used as our database was collected in comprehensive farm surveys. Using this database we derive costs of CO<sub>2</sub> mitigation by calculating income effects of land-use changes and contrasting them with the related reduction in greenhouse-gas emissions. For this we carry out farm-individual and plot-specific calculations. Our approach method and database 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.

## REGIONS OF STUDY



The two study regions R1 “Ahlenmoor” and R2 “Freising” 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”. The 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 contrast, in R2 UAA is used as grassland for forage and biogas-production of as well as arable land for cash crop, energy-crop and forage production.

Figure 1: Location of the sample regions (modified from Pfadenhauer & Drösler, 2005)

## **METHOD AND DATABASE:**

In our study we have built an economic model to calculate costs of adapted peatland management in German peatland regions. We aim to identify CO<sub>2</sub>-mitigating land-use strategies of peatland sites and to analyse farmers' income forgone resulting from the implementation of such strategies. Consequently we derive costs per ton CO<sub>2</sub> 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 CO<sub>2</sub>-mitigating land-use strategies**

The back-grounding data to identify potential land-use strategies which implicate relevant reductions of GHG-emissions originates from close co-operation with natural scientists from the project "Climate Protection – Strategies of Peatland Management" (Pfadenhauer & Drösler, 2005). In this project GHG-fluxes of common land-use strategies within representative German peatland sites are measured. 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<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) have to be considered. To derive total GWPs, additionally the import and export of C is included (Drösler et al., 2008). GWPs are quantified by the unit of carbon dioxide equivalent (CO<sub>2</sub>-C equiv.). GWP-factors for CH<sub>4</sub> and N<sub>2</sub>O correspond to the internationally accepted quantification of the Second Assessment Report (SAR) of the International Panel of Climate Change. According to SAR, CH<sub>4</sub>-C holds a multiplication factor of 7.6, N<sub>2</sub>O-N of 133. (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 (ER) can be expressed by CO<sub>2</sub>-equivalencies.

$$ER_{LU1 \rightarrow LU2} \text{ (in CO}_2\text{-C equiv.)} = GWP_{LU1} - GWP_{LU2}$$

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 described by Schaller & Kantelhardt (2009). To analyse the economic effects of emission-mitigating management strategies, at first the status quo of agricultural valued added on the sites had to be detected. For this, we analysed the current regional organisation (type of farming) of the farms and their individual land use. Based on this analysis, we

carried out farm-individual and plot-specific calculations of gross margin. By analysing potential changes of gross margin – as resulting from management changes – we derived losses of income.

#### *Regional farm organisation/ type of farming:*

The surveyed farms were classified according to standard gross margin (SGM) following the 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 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.

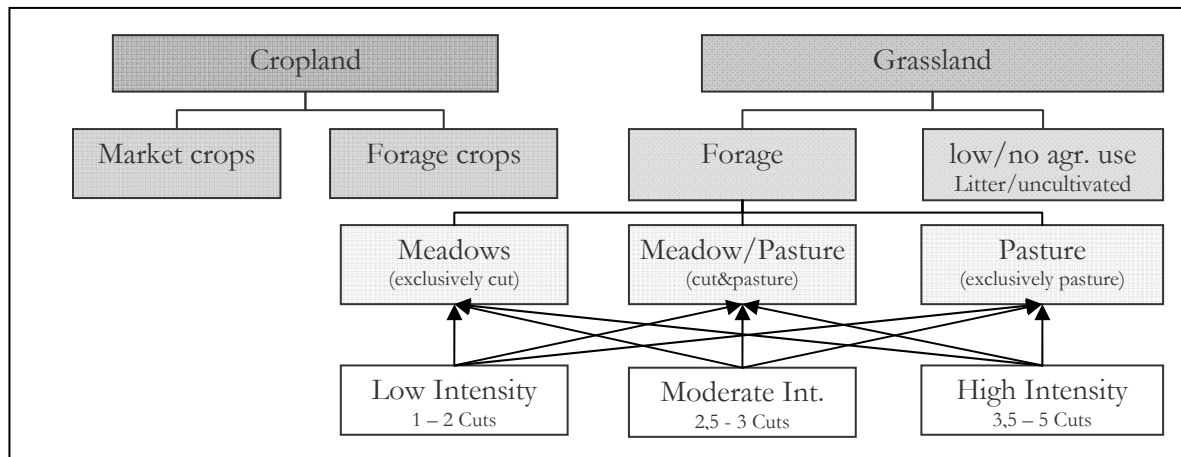
#### *Regional land use*

Corresponding to the variable types of farming, variable types of land use dominate within the regions. To analyse landuse-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<sup>1</sup>-crop production and **grassland** for a) forage<sup>1</sup> production or b) with no respectively with 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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<sup>1</sup> 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 2: 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 climate-friendly peatland management 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 resp. processing value, we fulfil the requirement to determine annual monetary values which correspond to an annual saving of CO<sub>2</sub> emissions (Dabbert, 2006).

Gross margin of **cropland for the production of market crops** (GM<sub>MC</sub>) is calculated by multiplying amount of crop output per hectare<sup>2</sup> with the regional market-price (“value of output”) and subtracting the cost of variable inputs<sup>3</sup> 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.

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

Direct designation of gross margin of **area used for forage production** (forage crops and grassland for forage production<sup>4</sup>) 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 (Hoffmann & Kantelhardt, 1998; Althoetmar, 1964). PC-Values can be 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<sub>HT</sub>) without costs for farm-produced forage. Divided by forage-nutrient-claims (NC) necessary to produce GM<sub>HT</sub>, the PC-Value per nutrient-unit (PC<sub>NU</sub>) is derived.

<sup>2</sup> Output in kg/ha: eg. kg/ha corn, wheat, barley, oats, rye, triticale, rapeseed, etc.

<sup>3</sup> Incl. costs of seed, fertilisers, plant protection, machine costs, harvest, fertilisation, insurance, drying, processing.

<sup>4</sup> 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.



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

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

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, AU<sub>i</sub> = Animal Unit of one husbandry type, N = Nutrients in forage diet, N<sub>SM</sub> = N from SilageMaize, N<sub>CG</sub> = N from cut grassland, N<sub>P</sub> = 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  $GM_{HTi}$ <sup>5</sup> (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

<sup>5</sup>  $GM_{HTi}$ 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.

of productivity (as described earlier) and under consideration of the farms individual production processes per ha ( $C_{ha}(LU)$ ). Subtracting the farms' individual costs of variable input<sup>6</sup> to produce  $NU_{ha}$  we determined a value for "GM<sub>HT</sub>-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<sub>2</sub>-equivalent

In order to identify cost-efficient strategies of climate-friendly peatland management 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 (per hectare and year). CO<sub>2</sub>-mitigation potentials of the recommended management-changes were delivered by the cooperating natural scientists and expressed in t CO<sub>2</sub>-C equiv. ha<sup>-1</sup>a<sup>-1</sup>.

The calculation of plot-specific costs follows the equation:

$$Costs / tCO_2equiv.^{-ha*a} = \frac{IF_{ha}(LU)}{t CO_2 - C equiv.^{-ha*a}} \quad (10)$$

## RESULTS:

The results of our study show that costs of CO<sub>2</sub> 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<sub>2</sub> emissions, it had already been demonstrated that the intensity of agricultural land use and the level of groundwater tables are the main factors which influence GHG emissions (cf. Byrne et al., 2004). The results of the GHG measurements carried out by our co-operating natural scientists confirm this assumption (Drösler et al., in prep.). According to them, the water table in particular dominates the exchange of CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> within the ecosystem: peat profiles which hold water tables close to the surface are characterised by anaerobic conditions below the mean water

<sup>6</sup> Farm individual costs of seed, fertilisation, plant protection, machine costs, harvest, fertilisation, insurance, drying, processing

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<sub>2</sub> and N<sub>2</sub>O emissions. Even if emissions of CH<sub>4</sub> are usually discontinued or are even changed to small CH<sub>4</sub> 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. In their results Drösler et al. (in prep.) prove that the 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<sub>2</sub>-C equiv. ha<sup>-1</sup>a<sup>-1</sup>. 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 of Drösler et al. reveal three major “mitigation steps”, as shown in Table 1. 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 1: Recommended land-use changes implying relevant GHG mitigation potentials

	<b>Initial land use</b>	<b>Target land use</b>	<b>GWP Mitigation Potential</b>
( 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)	+++

If we consider the results of Drösler et al. (in prep.), we see 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 became 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 2). Region 1 "Ahlenmoor" 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 (Schaller & Kantelhardt, 2009) 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 "Freising" 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 region R1, whereas the percentage among low, medium and high intensive grassland is nearly equal.

Table 2: Portrait of the study regions

<b>Farm organisation, type of farming (in percent)</b>	<b>R1 Ahlenmoor</b>	<b>R2 Freising</b>
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
<b>Peatland use (Percentage of peatland total):</b>		
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 (%) <sup>1</sup>	89	36

<sup>1</sup>) 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 3 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 generated via animal husbandry, we see that value added in R1 "Ahlenmoor" clearly exceeds value added on sites in R2 "Freising". The primary causes of this 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 value added 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 create remarkably higher  $PC_{GMHT}$ s compared to 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 husbandry, 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 3: Average<sup>1</sup>  $PC_{GMHT}$  and  $GM_{MC}$  of forage- and cash-crop land-use types (€ per hectare<sup>2</sup>)

	R1 "Ahlenmoor"	R2 "Freising"
<b>Cash crops</b>		
Total cash crops <sup>3</sup> :	-	464
<b>Forage production</b>		
Silage maize:	3877	1732
Grassland intensity high:	1894	1526
Grassland intensity moderate:	1706	851
Grassland intensity low: (agricultural utilisation)	867	479
Grassland intensity low: (maintenance) <sup>4</sup>	182	158

<sup>1</sup> weighted by amount of area

<sup>2</sup> Area payment included (federal target values 2013)

<sup>3</sup> Investigated cash-crops include winter wheat, winter barley, summer barley, winter rye, corn and oat.

<sup>4</sup> 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 the values added 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 levels of “status-quo” value added for different types of peatland use, is variation of the amount of income forgone for different levels of management changes. Table 4 presents the results of our study as regards agricultural income forgone which is associated with the implementation of the three potential steps recommended to mitigate GHG emissions. Furthermore, the table shows income forgone per t CO<sub>2</sub>-C equivalent derived by contrasting costs of implementation with the respective savings of CO<sub>2</sub> equivalents. When looking at the numbers, we see that in R1 almost continuously the costs per ton CO<sub>2</sub>-saving are higher than in R2. They range between €69 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<sub>2</sub>-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 about 30 t CO<sub>2</sub>-C equiv. ha<sup>-1</sup>a<sup>-1</sup>. 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<sub>2</sub>-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<sub>2</sub>-C equiv. ha<sup>-1</sup>a<sup>-1</sup>. 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<sub>2</sub>-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 were 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 4: Income forgone of recommended management changes (€/t CO<sub>2</sub>-C equiv.)

Land-use change	Initial Use	R1 Ahlenmoor		R2 Freising	
		Agr. Income forgone	Cost/t CO <sub>2</sub> – equiv.	Agr. Income forgone	Cost/t CO <sub>2</sub> – equiv.
( I ) Arable to GL high	CC	-	-	- 1062	-106
	SM	1983	1983	1342	268
( II ) (a) Arable/GL High to GL low agr.	CC	-	-	- 15	-1
	SM	3010	368	2389	128
	GLhigh	1027	126	1047	69
( II ) (b) Arable/GL High to GL low main.	CC	-	-	306	9
	SM	3695	130	2710	83
	GLhigh	1712	60	1241	48
( III ) Arable/GL High to restoration	CC	-	-	464	11 *
	SM	3877	134 *	2868	70 *
	GLhigh	1894	65 *	1526	41 *

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

To summarise briefly the results of our analysis, one can say that especially within regions where value added on peatland sites is high while mitigation potentials are comparatively low, income forgone and costs of water management per ton CO<sub>2</sub> 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 - even if economic costs appear to be high at first.

## DISCUSSION:

Our results show that income forgone per ton CO<sub>2</sub> mitigation can give hints for identifying the most cost-efficient measures of climate-friendly peatland management. 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 management 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 process 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 say that the range within the price per ton mitigated CO<sub>2</sub> equivalent will vary. Furthermore, it should be noted that even forage prices and land rents cannot be considered 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 rentable 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. Up to now 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.

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 (eg. intensified fertilisation, enhanced transport, land-use changes for the creation of alternative UAA, etc.). Therefore, for the derivation of macroeconomic and even global cost-benefit relations of a climate-friendly peatland management, profound scenarios involving effects within much broader system-boundaries would 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, even at the current stage of research our results show that regional basic conditions influence the costs of CO<sub>2</sub> 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<sub>2</sub> savings which balance income forgone, costs per ton CO<sub>2</sub> 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 climate friendly peatland management appears to be more cost-efficient or expensive. Particularly in regions where peatland 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 peatland 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 peatland area and high mitigation potentials, within such regions CO<sub>2</sub> mitigation via adapted peatland management might be a competitive way of protecting the climate. Generally, (again being aware of the limited system boundaries) compared to alternative techniques, the abatement\_costs we derived still display an acceptable range. Common abatement strategies, for example within the transport sector, cause



abatement costs that vary from 20 to 400 (eg. biodiesel, plant oils, cellulose-bioethanol, biogas) up to more than 1000 €/tCO<sub>2</sub> equiv. (bioethanol from wheat or sugar beet, hybrid drives). Also within the energy sector, abatement costs often exceed the €200 mark (eg. geothermal energy, electricity produced from biomass, hydropower) (Rauh, 2010).

Despite this potential competitiveness, as a final note it should be pointed out that in the case of CO<sub>2</sub> 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 climate-friendly peatland management. Consequently, in order successfully to implement measures to reduce GHG emissions from organic soils, it is necessary to implement adequate agro-environmental programmes to compensate resulting income losses.

## **SUMMARY AND CONCLUSION:**

Peatlands are the only ecosystems which durably store carbon. Consequently they are of the utmost importance for climate protection. Agricultural land use changes the function of peatlands as carbon sinks and can cause high emissions of the climate-burdening trace gases CO<sub>2</sub> and N<sub>2</sub>O. In Germany peatlands are the largest single source of GHG emissions **outside the energy sector** (NIR, 2010). In order to lower these greenhouse-gas emissions, a reduction in land-use intensity is necessary. In our study we analysed whether this option of GHG mitigation is a cost-efficient measure which can be recommended for implementation. For this, we investigated agricultural peatland management in six German peatland areas. To determine cost-efficiency, we conducted farm-individual and plot-specific calculations of agricultural income forgone resulting from land-use changes which are recommended to mitigate GHG emissions. By contrasting income forgone with CO<sub>2</sub> savings associated with the land-use changes, we derived income losses per ton CO<sub>2</sub> equivalent. Our results show that income forgone per t CO<sub>2</sub> 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 peatland sites is high while mitigation potentials are low, costs per ton CO<sub>2</sub> mitigation can result in being very high. In contrast, within regions that hold high mitigation potentials, changes of peatland management can be a cost-efficient strategy. Compared to alternative common abatement strategies, the costs we derived (ranging mainly between 50 and 250 €/t CO<sub>2</sub> 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 will be analysed and the system boundaries will be widened. During our study it became clear that a re-organisation of peatland use could provide fundamental benefits for society. However, in the case of CO<sub>2</sub> reductions, benefits appear to be social whereas costs are private. Against this background, the question arises as to how either social benefits can be monetarised in order to finance climate-friendly peatland cultivation strategies, or common instruments of agricultural politic can be used to subsidise the farmers' losses.

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