Leibniz Gemeinschaft

Final report

LandPaKT[1]
Agricultural Techniques: Potentials and Costs of Greenhouse Gas Mitigation

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[1] **Land**wirtschaftliche Verfahren: **P**otentiale und **K**osten der **T**reibhausgasminderung

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Executive Summary

The agricultural sector is a source as well as a sink of greenhouse gas (GHG) emissions, and hence has a relevant impact on climate change. For instance, in Germany, 7.4 % of national GHG emissions are attributed to farm activities. Mitigation options have often been analysed with a large-scale perspective and rarely at the farm level.

The LandPaKT project aimed at closing this gap with a systematic analysis and assessment of the most relevant mitigation approaches at the farm process level, namely rewetting of organic soils, management-dependent carbon sequestration in mineral soils, nitrogen fertilizer reduction, and animal husbandry, and their associated costs. The different options were to be integrated into a farm-level assessment, also considering economic effects for the farmers, in order to provide practice-oriented recommendations of efficient GHG mitigation at this level. As well, policy instruments were to be analysed offering an efficient tapping of the identified GHG mitigation potentials in agriculture. The project was organized as a joint PhD graduate school of the *Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) Potsdam* and the *Faculty of Life Sciences at the Humboldt-Universität zu Berlin*, in particular four divisions of the *Thaer Institute (Soil Science and Site Science, Agronomy and Crop Production, Agricultural Policy, Strategies for Using Bioresources)*. Its curriculum consisted of three consecutive topic-related as well as several soft skill courses, and periodical exchange in order to foster an enhanced understanding of the farm level approach for the PhD candidates. The seven theses dealt with: the rewetting of organic soils and effects on GHG emissions (1) as well as adapted use of rewetted sites (2), the optimized cultivation of mineral soils (3), the analysis of mitigation measures in animal husbandry (4) and a consistent balancing methodology (5), as well as analyses at the process level (6) and options for agricultural policy (7).

At the time of this reporting, not all theses were finalized. However, from available results it can be stated that changing soil management systems, both in organic and mineral soils, can provide GHG mitigation potentials, even though these are inevitably associated with costs, especially on organic soils. Farms on mineral soils have at least some options to adapt their management systems without negative economic effects. Nitrogen (N) fertilizer reduction, especially on mineral soils, does not only mitigate GHG emissions but also other negative environmental impacts of agriculture, for instance N leaching. Such joint effects could be triggered cost-efficiently by marginal N reduction, if crop- and region-specific yield responses are reflected as well as product quality effects are internalized. Modelling approaches are available that help to derive the appropriate fertilization schemes at low opportunity costs. Animal husbandry, and in particular ruminants husbandry, is by nature affiliated with GHG emissions. However, some mitigation potentials exist in the management, especially in the choice of feed composition and related land use choices.

A relevant pre-condition for all reliable analyses in the agricultural context was and is the availability of high-quality, long-term data on different sites and different crops (yields, management, emissions). The project consortium is therefore deeply grateful to all institutions which provided data for the work packages.

1 Research Questions and Objectives of the Project

The agricultural sector is a source as well as a sink of greenhouse gas (GHG) emissions, and hence has a relevant impact on climate change. For instance, in Germany, 7.4 % of national GHG emissions are attributed to farm activities[2]. Main sources are mineral and organic soils, enteric fermentation of ruminants and manure management. Agriculture can mitigate GHG by carbon sequestration in soils or by providing biomass as a substitute for fossil energy carriers. The diversity of existing mitigation options and the large number of actors in the agricultural sector makes it difficult to tap these potentials. Furthermore, measuring and monitoring emissions and sequestration effects is laborious and time-consuming. Mitigation options have often been analysed with a large-scale perspective and rarely at the farm level. Especially the interactions between different measures and their associated implementation costs have been omitted.

Rewetted organic soils under agricultural use call for integrated process chains for site management as well as for biomass use. This includes adaption of machinery, for instance for limited carrying capacity of rewetted soils and late harvest of biomass as well as suitable energy or material usage technologies of the newly adapted plant communities due to high(er) groundwater tables. The most relevant GHG mitigation options, and associated costs and benefits need to be analysed. The amount of GHG emission reductions on extensively managed grassland after different times of rewetting needs to be identified. The relevant factors that influence the different GHG fluxes need to be assessed, considering changes in vegetation cover and species composition.

Cultivation of mineral soils can mitigate GHG emissions by optimized nitrogen (N) fertilization, reduced tillage, improved humus and water management[3], all of which can reduce N_2O emissions. Carbon (C) accumulation in soils offers CO_2 sequestration effects which need to be analysed from long-term measurements of C contents as well as GHG emissions. For farm-level recommendations, the mitigation effects of the different driving factors need to be distinguished as well as integrated in farm cost models.

Animal products such as milk and meat are characterized by high product-specific GHG emissions. With an increasing world population and aligning consumption patterns, the emissions associated with **animal husbandry** need urgent reductions. Emissions are mainly from enteric fermentation of ruminants (cows, sheep etc.) as well as from manure management and especially the feed cultivation. Existing analyses address single process steps or single keeping systems. A systematic quantification of the overall effectiveness of GHG mitigation measures, their costs as well as a-priori assessments of innovations is still lacking.

Furthermore, GHG emissions and their mitigation can be calculated according to different **methodologies** which hinder comparisons and integration of results of different studies. Similarly, mitigation costs at the farm level have been rarely calculated according to a common methodology even though comparative mitigation costs offer a high potential to identify optimal site-specific techniques. For **policy assessment**, the identification of abatement cost curves is essential.

The LandPaKT project aimed at a systematic analysis and assessment of the most relevant mitigation approaches at the farm level, namely soil use and animal husbandry and their associated costs. The distinct options at the process levels (rewetting of organic soils, management-dependent carbon sequestration in agricultural soils and husbandry) were to be integrated into a farm-level assessment in order to provide practice-oriented recommendations of efficient GHG mitigation at this level. As well, policy instruments have

[2] NIR Germany 2017; accessed at 09.10.2017 https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-05-02_climate-change_14-2017_nir-2017_unfccc_eng.pdf

[3] Smith, P. (2012): Agricultural greenhouse gas mitigation potential globally, in Europe and in the UK: what have we learnt in the last 20 years? Global Change Biology 18, 35-43

been analysed which offer an efficient tapping of the identified GHG mitigation potentials in agriculture.

The project partners, Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) and Humboldt-Universität zu Berlin (HU), aimed at increasing their collaboration with regard to a structured promotion of young scientists at both institutions as well as from cooperating institutions, at intensifying the networking between ATB and Thaer-Institute for Agricultural and Horticultural Sciences (former Agricultural-Horticultural Faculty), and at jointly advancing their strategically important competences in research for a resource-efficient agriculture.

Topic-related courses aimed at a goal- and PhD-project-oriented education. The participants of the joint Leibniz Graduate School (LGS) should gain a shared understanding of the system which they analyse. The regular meetings and periodical exchange should enhance the methodical matching of the different PhD projects. Additionally, they should benefit from the close cooperation with other scientific institutions in the metropolitan area (for instance Potsdam Research Network - pearls, Potsdam Graduate School - PoGS, Humboldt Graduate School - HGS, TU and FU Berlin, Potsdam Institute for Climate Impact Research e.V.- PIK, and Leibniz Centre for Agricultural Landscape Research - ZALF).

2 Progress of Work Packages

General

The project started on May 1st 2013. Due to a postponed signing of the official cooperation agreement between ATB and HU, the job postings for the PhD positions at both partners were delayed which in turn resulted in late recruitment. PhD candidates started in May, June and July 2013 (ATB) and August, September 2013 and April 2014 (HU). The kick-off was scheduled after the recruitments of most LGS members (October 29th 2013), and the curriculum started in December 2013 in order to allow all members to participate. This postponement propagated throughout the complete curriculum.

Curriculum

Besides working on their specific PhD projects (see further below), the LandPaKT members attended courses in the LandPaKT curriculum which consisted of topic-related courses as well as soft skill courses. Prior to the three mandatory content-related classes, a short workshop was held to develop a logo for the graduate school and to get to know each other. The workshop resulted in an agreed-on draft that was then used for representing the LGS LandPaKT in the upcoming years (see title page).

During three terms, topic-related courses were held by specialists in the respective fields from ATB, Thaer-Institute, external experts, as well as PhD candidates themselves. The classes focused on methods ("Measuring & Balancing of GHG"), emission sources and mitigation options ("Sources & sinks of GHG in agriculture") as well as integrated “System analyses”. They took place as lectures, tutorials as well as field trips. Courses were open to interested colleagues and PhD candidates at both and external institutions, and the schedule was distributed via mailing lists and on the project web page[4]. Participation was mandatory to earn the credits according to the Doctoral Degree Regulations at the Faculty of Life Sciences at the HU.

The first course started with a field trip to a dried, cultivated fen, followed by a lecture on methods to measure GHG emissions in the field and laboratory. Based on the knowledge of the method "Life Cycle Assessment", the third lecture dealt with the balancing of GHG specifically. Basic knowledge of economic concepts with the focus on agricultural farms was imparted in order to calculate GHG mitigation costs. Long-term experimental sites on sandy soils in Berlin-Dahlem and Thyrow were visited, after understanding the theory of how the carbon stocks and stock changes in soils are measured and calculated. The basics of how GHG are produced in ruminants and how they can be measured directly in the animal and in

[4] https://landpakt.atb-potsdam.de (German), https://landpakt.atb-potsdam.de/en/landpakt/mission.html (English)

the stable could be observed in the Leibniz Institute for Farm Animal Biology (FBN) and the neighbouring Manor Dummerstorf. How administration and policy can tap full mitigation potentials at the farm level was finally intensely discussed at the agricultural policy division at the HU. The specific requirements of data collection at the farm level were dealt with in the last lesson, for instance regarding data protection.

During the second seminar, the PhD candidates presented the relevant sources and sinks of their specific research topic. Starting with the cultivation of organic soils, its numerous management options were analysed and compared using the methodological know-how of the first seminar. Which specifications have to be considered when addressing sandy soil, which is a main soil type in Brandenburg, were the topic of the second seminar. This course took place at the division of agronomy and crop production in Berlin-Dahlem.

The animal husbandry, with the focus on dairy cattle, offers options to reduce GHG emissions. Regional conditions may have an important influence as was demonstrated for datasets from Norwegian organic farms during one seminar. Another dealt with options to reduce the direct emissions from the animals as well as their physiological limitations. Land use change effects from variations in animal diets were dealt with during the following meeting. Varying yield response to N-fertilization modifications, and resulting changes in the mitigation costs at the regional level were discussed in a seminar as well as modelling tools to assess several farms (FARMIS model[5]). The module closed with discussion of present know-how on GHG emissions from two rewetted plots in Brandenburg.

The third seminar aimed at widening the topic-specific analyses to a system-wide view. Existing system analyses were compiled and own results put into relation. How to deal with uncertainties and to connect information from different scales was of specific interest. Once again, land use change effects and balancing challenges had to be dealt with.

Indispensable skills for a scientific career, such as “English as a scientific language” or “Organizing scientific meetings” were improved and consolidated in courses and workshops which are already established in the trainee programs of the ATB and the Humboldt University (Humboldt Graduate School). Teamwork and acquisition of funding for instance were developed during the organization of the 8th AgrosNet-PhD-Day 2015[6]. This event was autonomously organized by the LandPaKT members. Conference venue was in the historical buildings of the Humboldt-Universität zu Berlin. PhD candidates of three East-German universities and research institutes came together to discuss their projects and to identify co-operation options. On the occasion of the International Soil Year, the conference motto was “Let's talk about soil.[7]” Further improvement of soft skills, like “Publishing/Presenting scientific results”, “Peer-Reviewing of scientific articles” or “Tutoring students” was optional, depending on individual needs. Learning on the job was prioritised over courses in order to be able to focus on one's own scientific research activities. Each seminar series concluded with a feedback meeting or follow-up questionnaire. All PhD candidates successfully passed the LandPaKT curriculum in accordance to faculty guidelines.

Single PhD proposals

Organic Soils - Effects of Rewetting

The position was staffed in August 2013 with a candidate already experienced in GHG measurements in the field. Subsequently, possible experimental sites of rewetted fens in agricultural areas around Berlin/Potsdam were identified. For two of them (six and 18 years after rewetting), the approval for accession was obtained from landowners and the official nature protection administration. As well, necessary experimental equipment for on-site GHG measurements of CO_2, CH_4 and N_2O was obtained. Field measurements in bi- and tri-weekly cycles started in May 2014 and went on until June 2016. These measurements showed that

[5] https://www.thuenen.de/en/infrastructure/the-thuenen-modelling-network/models/farmis/
[6] https://landpakt.atb-potsdam.de/en/meta/events.html#CID8035
[7] The animago-award-winning animation film "Let's talk about soil" was shown, which is available in several translations on the Vimeo-channel of the Institute for Advanced Sustainability Studies Potsdam e.V.
https://vimeo.com/iasspotsdam/videos/page:4/sort:date

two-year measuring periods might be too short due to varying weather conditions. Damage caused by wild boars was fixable by introducing again pore water pressure cells prior to next measurements.

Vegetation mapping took place from April through July 2016. Soil parameters were assessed in summer 2016 and experimental equipment in the fens dismantled except for the groundwater monitoring pipes, which are furthermore in use by the site owners *Landschaftsförderverein Nuthe-Nieplitz-Niederung* and *Flächenagentur Brandenburg*. Gas flow calculation and modelling need to be completed, as well as the mosses and vegetation monitoring, the identification of prior land use at the research sites, and the dissolved carbon fraction in the ditches. Groundwater levels proved to be challenging to regulate due to difficult adjustment of the water retaining structures. In 2018, the supervision agreement was terminated.

Organic Soils - Adapted Use of Rewetted Soils

The PhD candidate started in July 2013 with a comprehensive meta-analysis of published emission data of CO_2, CH_4 and N_2O from agricultural soils, categorized to different land use systems of fens in the temperate climate zone. This information on soil emissions was complemented by complete emission assessments for the different feasible management systems of the land use systems including plant production, livestock husbandry and bioenergy generation, totalling 20 different fen management options.

After contacting land owners of rewetted fens as well as biomass conversion facilities in the Brandenburg/Berlin area, temperature loggers were installed on identified plots in winter seasons 2013/16 to identify frost periods ex-post. In these seasons, sufficiently low temperatures were not reached at the different test sites. Therefore, the respective work package and experiments to test soils for trafficability were substituted by a theoretical analysis of costs, income and profit for the different land use and management systems on fenlands in Germany from the previous work package. This information was merged with the emission data to assess the mitigation costs associated with the rewetting of agricultural fens to different agricultural land use options.

Mineral Soils – Factor Intensities

The PhD candidate started in September 2013 by analysing available data on fertiliser management from long-term experiments at research stations in Berlin-Dahlem and Thyrow. Crop rotation and straw fertilisation experiments in Thyrow were identified as the most promising ones. Available results of nitrous oxide emissions in Thyrow allowed adapting the German NIR[8] methodology to the specific conditions of sandy soils in Brandenburg, and as a result calculating GHG balances for different crop rotations, straw as well as mineral nitrogen fertilisation.

A literature survey returned no common accounting methodology of changes in soil organic carbon (SOC) in such GHG balances. The experimental design and available data in Thyrow did not allow testing the different accounting approaches. As a consequence, an agreement was signed with the Landesamt für ländliche Entwicklung, Landwirtschaft und Flurneuordnung des Landes Brandenburg (LELF) to use long-term data from its research station in Groß Kreutz where since 1967 a nitrogen combination experiment provides complete data sets and numerous publications. These data were used to test different approaches for SOC changes in GHG accounting. As well, the impact of increasing mineral and organic nitrogen fertilisation on GHG emissions could be tested.

The adapted methodology was applied in a case study for sandy soils, where the data of a 2700 ha farm in Brandenburg with more than 14 different crops from 2010-14 were analysed to identify GHG mitigation potentials and their economic impact for the farm.

[8] National Inventory Report

Catalogue and Effectiveness of Mitigation Measures

The PhD student started in May 2013 with an analysis of published methodologies and data on GHG emissions and their mitigation on dairy farms. The system boundaries of the review study reached from feed cultivation to manure application on the field and included dairy cows as well as calves and heifers for stock reproduction. The related GHG emissions were calculated according to IPCC methods also used for the calculation of the German emission inventory (Rösemann et al. 2017[9]). Based on these methods and on farm data, the influence of different feeding and management strategies on CH_4 emissions from enteric fermentation as well as from manure and N_2O emissions from feed cultivation should be analyzed. Data were acquired from dairy farms and CH_4 emissions were calculated.

The PhD candidate dismissed her plan to graduate for individual reasons at the end of the project phase.

Methodology of GHG Balancing

The position was staffed in June 2013 with a PhD candidate already experienced in life cycle assessment and GHG balancing. This thesis was closely related to the previously mentioned catalogue thesis and hence, work load increased after the cessation of the former. The analysis started with the adaptation of existing diet data sets and models for dairy cows in order to assess effects of optional land use change due to increasing milk yields through modified feed mixtures. This adaptation took more time than previously projected. Hence, planned work package three on methodological recommendations was reduced. After the specification of the diet mixtures, GHG emissions per product unit milk were assessed for a wide variety of milk yields. This comprehensive data set was analysed in a joint Monte Carlo study during a stay at the Animal Production Systems Group of the Wageningen University/Netherlands in order to analyse the impact of different variable parameters (system assumptions, naturally variable parameters) on the GHG emissions of milk.

Analyses at the Process Level

The PhD candidate started in June 2013. N fertiliser reduction has often been mentioned as an effective measure for GHG mitigation at the farm level. However, crop yields response differently to N reduction, and the costs of GHG mitigation by N fertiliser reduction need to be identified considering differences in economic return for the farm. Consequently, existing yield-N-response modelling approaches were screened and their input data demand evaluated. Hence, a model approach was developed to identify comparative cost structures for five different yield zones in Brandenburg[10] and was tested for two major cereal crops (winter wheat and winter rye) which are common in that specific region. Yield data were available from long-term experiments in Berlin-Dahlem. Furthermore, yield responses to N for different crops at different sites were estimated using a dynamic, process-based plant growth simulation model (MONICA[11], Leibniz-Zentrum für Agrarlandschaftsforschung e.V.). The approach was also applied to assess the economic advantage of site-specific N management vs. uniform N management on winter wheat, when N supply is limited by legislation.

Agricultural Policy

This position was staffed in April 2014. After a screening of existing models on GHG and agriculture at different scales (macroeconomic models, sector-specific models, single-farm models), the PhD candidate familiarised himself with the FARMIS model of the Thuenen-Institute of Farm Economics in Braunschweig, which is a comparative-static programming model for farm groups based on information from the farm accountancy data network

[9] Rösemann C, Haenel H-D, Dämmgen U, Freibauer A, Döring U, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, Osterburg B (2017): Calculations of gaseous and particulate emissions from German agriculture 1990-2015: report on methods and data submission 2017. Braunschweig: Thünen-Institut, 424 p, Thünen Rep 46; http://literatur.thuenen.de/digbib_extern/dn058465.pdf

[10] Datensammlung für die betriebswirtschaftliche Bewertung landwirtschaftlicher Produktionsverfahren; http://lelf.brandenburg.de/media_fast/4055/Datensammlung%202016_web.pdf

[11] MOdel of Nitrogen and Carbon dynamics in Agro-ecosystems; http://monica.agrosystem-models.com/index.php

(FADN). This model was extended with a GHG module in order to calculate GHG emissions according to the national accounting rules (Rösemann et al. 2017[12]). Using data from KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V.), different production intensities of crop cultivation techniques were categorized. The relative share of the agricultural land use type “drained organic soils” was derived by intersection of maps of the Federal Institute for Geosciences and Natural Resources and Federal and State Statistical Offices.

With this model extension, the reference scenario (Thünen baseline[13]) can be analysed, as well as the suitability and relevance of different GHG mitigation strategies on income, production amounts and GHG emissions of agriculture, with special consideration of farm adaptation strategies.

3 Results and Discussion

Organic Soils - Effects of Rewetting

Due to the ongoing data analysis, no detailed results and discussion can be presented at this time of reporting.

Organic Soils - Adapted Use of Rewetted Soils

The most promising measure with respect to GHG emission reduction was rewetting of organic soils in temperate regions by raising groundwater levels of formerly drained peatland. Management-driven emissions were of minor importance, whereas direct emissions from soil (CO_2 and CH_4) were the most relevant. Rewetting formerly intensively used cropland accounted for the complementary trends of CO_2 emission reductions vs. CH_4 emissions increases. However, the necessarily adapted agricultural management systems of such areas were only profitable if affected farmers in these regions were compensated for economic losses by adjustment payments.

Mineral Soils – Factor Intensities

GHG mitigation potentials on sandy soils in Brandenburg exist for an increase in organic fertilisation, for instance by manure application. Besides the increase of organic matter in soils and the accompanying soil fertility, this farm measure reduces GHG emissions. As expected, the highest reduction potentials stem from reduced mineral nitrogen fertilisation, especially if substituted by organic fertilisers. The proper design of the crop rotation can as well increase soil organic matter contents and mitigate GHG. However, the specific amounts need to be analysed further. The application of different available approaches to account for soil organic carbon changes resulted in relevant differences in GHG balances and accordingly in the mitigation potentials. Therefore, the development of a common accounting approach is strongly recommended.

From the case study it became clear that exploitation of GHG mitigation potentials calls for a change in soil use systems. The cultivation of emission-intensive crops with a high mineral N input, for instance winter rape, needs to be reduced, and low-emission crops need to be grown. For the case study farm, maize with organic N-fertilisation as well as legume cropping had especially low emissions. Such emission-optimized cultivation schemes do not necessarily result in negative economic effects for the farm, if accounted for already in the management planning phase.

[12] Rösemann C, Haenel H-D, Dämmgen U, Freibauer A, Döring U, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, Osterburg B (2017): Calculations of gaseous and particulate emissions from German agriculture 1990-2015: report on methods and data submission 2017. Braunschweig: Thünen-Institut, 424 p, Thünen Rep 46; http://literatur.thuenen.de/digbib_extern/dn058465.pdf

[13] Offermann F, Banse M, Deblitz C, Gocht A, Gonzalez Mellado AA, Kreins P, Marquardt S, Osterburg B, Pelikan J, Rösemann C, Salamon P, Sanders J (2016): Thünen-Baseline 2015-2025: Agrarökonomische Projektionen für Deutschland. Braunschweig: Thünen-Institut, 116 p, Thünen Rep 40; http://literatur.thuenen.de/digbib_extern/dn056473.pdf

Catalogue and Effectiveness of Mitigation Measures

The analysis of the farm data showed rather similar diet compositions even though milk yields of the cows were different. Grass silage, maize silage and concentrate feed were the main components in all investigated diets. Only the ratio of grass to maize silage depended on site conditions. Maize silage was the predominant feed component on farms with a lower share of grassland. Despite these different shares of single diet components, emission determining ingredients (crude fiber, nitrogen free extracts, crude protein and fat) were very similar. As a consequence, methane emission from enteric fermentation alone, calculated according to the method mentioned above, was mainly influenced by the milk yield. With increasing milk yields, the methane emission per kg milk decreased. However, this effect diminished at higher milk yields (30 kg milk cow^{-1} day^{-1}).

Methodology of GHG balancing

A combined local and global sensitivity analysis identified the CH_4 emission factor of enteric fermentation, milk yield, feed intake, the direct N_2O emission factor of crop cultivation and the N_2O emission factor for grazing as the essential parameters for the assessment of GHG emissions of milk production while accounting for correlations and using a systematic approach. Increasing overall milk production needed more land, however this effect might be diminished by increasing the cows' milk yields if at the same time diets are more grassland-based.

Analyses at the Process Level

The marginal reduction of N fertilizer application offered GHG mitigation potentials at low opportunity costs. However, cost structures of GHG mitigation by N reduction varied for different crops at different sites. In a given region, the allocation of N reduction could be optimized to improve cost-efficiency of GHG mitigation.

The use of a crop growth simulation model enabled to identify differentiated yield response functions for various crops and sites, so that N fertilizer reduction scenarios could be run.

N fertilizer reduction was achievable at lower abatement costs with site-specific N management (SSNM), whereas economic advantage of SSNM diminished with increasing N supply restriction, unless product quality was affected. Higher economic benefits can be expected, if SSNM results in positive effects on grain quality and thus higher crop price. Further potential advantages of SSNM include lower costs for monitoring and registering N fertilizer reduction. Importance of SSNM can be higher, if positive external effects (e.g. lower N leaching and GHG emissions) are internalized.

Agricultural Policy

Modelling the baseline emissions (3-year mean of 2010-12) and baseline 2023 indicated an appropriate combination of balances with internal farm variables and parameters.

In the following, specific policy instruments, such as quota, taxes or fees on nitrogen surplus will be implemented, in order to analyse their potential on efficient and effective exploitation of GHG mitigation potentials in agriculture.

4 Commercial Relevance

No transfer of results of the single dissertation studies or of the complete graduate school project is possible into economic applications. No patents were applied for or cooperation with economic partners agreed on.

5 Contributions of Partners in Germany and Abroad

Landschaftsförderverein Nuthe-Nieplitz-Niederung and *Flächenagentur Brandenburg* provided information on water stages and vegetation maps at the experimental sites in the rewetted fens. *HNE Eberswalde* and *Leopold Siegrist GmbH* lent experimental equipment for for water flow measurements in ditches and H_2S measurements, respectively. *Ingenieurbüro*

Naturschutzkonzepte, *Landesamt für Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg*, and *working group Botanik und Arboretum, Institut für Biologie, Lebenswissenschaftliche Fakultät, Humboldt-Universität zu Berlin* supported the vegetation and soil mapping, and moss identification, respectively. The *University of Rostock* (Working group *Landscape Ecology and Site Evaluation* under the direction of Prof. Dr. S. Glatzel) lent transparent chambers and frames for carbon dioxide flux measurements. The *Leibniz-Institute of Freshwater Ecology and Inland Fisheries* (IGB) supported the measurement of sulphate concentrations in soil pore water samples.

The *Landesamt für ländliche Entwicklung, Landwirtschaft und Flurneuordnung des Landes Brandenburg* (LELF) cooperated intensely with the LandPaKT project and provided important long-term experimental data. A farm provided comprehensive farm data for use in a case study.

The *Animal Production Systems Group of the Wageningen University/Netherlands* cooperated in the way that an exchange of PhD candidates working on the methodology of considering uncertainty in GHG calculation from dairy farming was facilitated. LandPaKT members spent a research stay in Wageningen as well as a Dutch PhD candidate worked at ATB, which finally resulted in a joint publication (see 7).

The *Danone Deutschland GmbH, Haar/Germany* and the *Leibniz Institute for Farm Animal Biology (FBN) Dummerstorf/Germany* contributed with farm data and experimental analyses of the relation between the feeding of dairy cattle and the release of methane.

The *Förderverein für Agrar- und Gartenbauwissenschaften an der Humboldt-Universität zu Berlin e.V* supported the organization of the 8th AgrosNet-PhD-Day which took place in Berlin in 2015.

The *Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V. (Müncheberg/Germany)* contributed with MONICA[14] a dynamic, process-based plant growth simulation model that served as an alternative approach to evaluate yield penalties due to nitrogen fertilizer reductions.

The *TI-Institute of Farm Economics Braunschweig/Germany (Johann Heinrich von Thünen Institute - Federal Research Institute for Rural Areas, Forestry and Fisheries)* provided with its comparative-static programming model FARMIS for farm groups based on information from the farm accountancy data network (FADN) the opportunity to assess the implications of nation-wide mitigation policy effects for different farm types.

6 Finalized Theses

The following, fully financed dissertations were finalized/are to be submitted to the Faculty of Life Sciences at the Humboldt-Universität zu Berlin:

Rebhann, M.: *Bewirtschaftung von Niedermooren in der gemäßigten Klimazone: Treibhausgasemissionen und Rentabilität*. Monography; Online available: http://dx.doi.org/10.18452/19334 Supervisor: Prof. Dr. A. Prochnow

Wolf, P.: *Methodology for assessing greenhouse gas emissions from dairy production - including the production of fodder and land use changes (Working Title)*. Monography; submission planned for autumn 2018. Supervisor: Prof. Dr. A. Prochnow

Klepatzki, J.: *Treibhausgasminderung auf Sandböden – Potenziale in verschiedenen Nutzungssystemen*. Monography; 2017. Supervisor: Prof. Dr. F. Ellmer. Online available: https://doi.org/10.18452/18614.

Braun, J.: *Der Einbezug des Agrarsektors in die Klimaschutzpolitik - Ökonomische Konsequenzen anhand quantitativer Modellierung mit FARMIS zu Auswirkungen von THG-*

[14] **MO**del of **Ni**trogen and **Ca**rbon dynamics in **A**gro-ecosystems

Minderungsstrategien in Deutschland. Monography; submission planned for 12/2018. Supervisor: Prof. Dr. D. Kirschke

Karatay, Y.N.: *Nitrogen fertilizer reduction as a cost-efficient option for greenhouse gas mitigation*. Monography; submission planned for 12/2018. Supervisor: Prof. Dr. D. Kirschke

Associated theses and dissertations:

Schneider, K. (2016): *Im Ernst jetzt?! – Potenziale von Serious Games für den Wissenserwerb*. Technische Universität Berlin, Geistes- und Bildungswissenschaftliche Fakultät, Medienwissenschaft. 19.09.2016; Masterthesis. Co-supervisor: A. Hansen.

Schüler, M.: *Using Life Cycle Assessment in Agriculture – Methodological considerations of variability and uncertainty in dairy carbon footprints.* Publication-based dissertation; submitted in August 2018. Supervisor: Prof. Dr. A. Prochnow

Ponstein, H.: *Bewertung der Treibhausgasemissionen der Weinproduktion*. Publication-based dissertation; submission planned for 2019. Supervisor: Prof. Dr. A. Prochnow

7 List of Publications and Presentations

[bold print: LandPaKT members]

2018

Karatay, Y.N., Meyer-Aurich, A.: *Climate smart reduction of N fertilizer for a cost-efficient GHG mitigation*. International Conference on Agricultural GHG Emissions and Food Security –Connecting research to policy and practice. September 10-13, 2018 in Berlin/Germany (Presentation)

Karatay, Y.N., Meyer-Aurich, A.: *A model approach for yield-zone-specific cost estimation of greenhouse gas mitigation by nitrogen fertilizer reduction*. Sustainability 10(3): 710. DOI 10.3390/su10030710

Karatay, Y.N., Meyer-Aurich, A., Gandorfer, M.: *Ökonomik der teiflächenspezifischen Düngung von Weizen unter Berücksichtigung von Qualität, Risiko und Stickstoffdünge-restriktionen*. GIL-Annual conference (Gesellschaft für Informatik in der Land- Forst- und Ernährungswirtschaft e.V.). February 26-27, 2018 in Kiel/Germany (Presentation).

Hansen, A., Schneider, K., Lange, J.: *Games for Knowledge Transfer and Stimulus for Climate Change Mitigation in Agriculture - Lessons learned from a Game Prototype* In: Walter Leal Filho (Hrsg.): Handbook of Climate Change Communication. Berlin (Vol. 3.) p.197-208, Heidelberg: Springer Berlin Heidelberg. DOI 10.1007/978-3-319-70479-1

Schüler, M., Hansen, S., Paulsen H-M.: *Discrimination of milk carbon footprints from different dairy farms when using IPCC Tier 1 methodology for calculation of GHG emissions from managed soils*, Journal of Cleaner Production 177: 899-907, DOI 10.1016/j.jclepro.2017.12.227

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Karatay, Y.N., Meyer-Aurich, A., Gandorfer, M.: *Economic potential of site-specific N fertilizer application when N supply is restricted*. EFITA World Congress. July 3-5, 2017 in Montpellier/France (Presentation; awarded with “Best Oral Student Communication”).

Schüler, M., Paulsen, M., **Berg, W., Prochnow, A.:** *Accounting for inter-annual variability of farm activity data for calculation of greenhouse gas emissions in dairy farming*. The International Journal of Life Cycle Assessment, DOI 10.1007/s11367-017-1307-x.

Hansen, A. et al.: *LandPaKT Game - A Prototype for Climate Change Mitigation in Agriculture*. World Symposium on Climate Change Communication. February 22-24, 2017 in Manchester/UK (Poster).

Schüler, M., Paulsen H. M., Koesling, M.: *Funktionelle Einheit in der Milch-Ökobilanz - Berechnung des Referenzflusses*. Wissenschaftstagung Ökologischer Landbau. 10.03.2017 in Freising-Weihenstephan/Germany.

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Braun, J.; Kirschke, D.; Offermann, F. (2016): *Ökonomische Modellierung von Politikansätzen zur THG-Vermeidung im Agrarsektor – Auswirkungen von Lachgas- und Methanminderungspolitiken auf Betriebsebene in Deutschland*. In: Kühl, R.; Auerbacher, J.; Herrmann, R.; Nuppenau, E.-A.; Schmitz, M. (Hrsg.): Perspektiven für die Agrar- und Ernährungswirtschaft nach der Liberalisierung. 55. Jahrestagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaus e.V. Gießen 2016 – ISBN: 978-3-7843-5463-7 (based on poster)

Karatay, Y.N., Meyer-Aurich, A.: *N fertilizer reduction as cost-efficient GHG mitigation with respect to regionalized crop yield response*. TradeM International Workshop, October 2016 in Trondheim, Norway (Presentation).

Klepatzki, J.: *Kohlenstoffvorräte und Treibhausgasbilanzen sandiger Ackerstandorte* Presentation at workshop „Nachhaltige Sicherung der Humusgehalte und Bodenfruchtbarkeit unter Beachtung von Klimawandel und EU-WRRL“, Landesamt für Umwelt, Landwirtschaft und Geologie in Nossen/Germany. March, 2016. Online available: https://www.landwirtschaft.sachsen.de/landwirtschaft/41557.htm

Klepatzki, J.; Ellmer, F.: *Treibhausgasemissionen bei der ackerbaulichen Nutzung von Sandböden*. In Mitt. Ges. Pflanzenbauwiss. 28. (2016). 114-115.

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Schüler, M.: *Ökobilanzierung zur betrieblichen Entscheidungsunterstützung: das FARMModell in Umberto.* Presentation at Expertenworkshop „Nachhaltigkeitsbewertung und -management in der Landwirtschaft“, February 2016 in Kleve/Germany.

Wolf, P., Groen, E., **Berg, W., Prochnow, A.**, Bokkers, E.A.M., Heijungs, G., de Boer, I.J.M.: *Assessing greenhouse gas emissions of milk production: which parameters are essential?* The International Journal of Life Cycle Assessment. DOI 10.1007/s11367-016-1165-y.

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Braun, J., **Kirschke, D.**, Offermann, F.: *Economic Modelling of GHG-Mitigation Policies - Impacts of Nitrous Oxide Mitigation Strategies at Farm Level in Germany*. Presentation at 6th EAAE PhD-Workshop. 8-10 June 2015 in Rome/Italy.

Hansen, A.: *Herausforderungen in der Koordination strukturierter Graduiertenprogramme*. Presentation at „Vernetzungstreffen der Koordinator/innen von Leibniz Graduate Schools und strukturierten Promotionsprogrammen“ at Leibniz-Gemeinschaft 8. October 2015 in Berlin/Germany.

Hansen, A., **Prochnow, A.**, Hassenberg, K.: *Strukturierte Promovierendenförderung*. Presentation at ATB-internal meetings in January & February 2015 in Potsdam/Germany.

Hansen, A., **Holz, K.**, **Karatay, Y.N.**: *Wie geht und was kostet eigentlich Klimaschutz in der Landwirtschaft?*. Poster und Spiel auf der Langen Nacht der Wissenschaften am 13. Juni 2015 in Berlin-Dahlem/Germany.

Hansen, A., **Holz, K.**, **Karatay, Y.N.**: *Wie geht und was kostet eigentlich Klimaschutz in der Landwirtschaft?*. Poster und Spiel auf dem Potsdamer Tag der Wissenschaften am 9. Mai 2015 in Potsdam/Neues Palais/Germany.

Hansen, A.: *Spiele zur Kenntnisvermittlung und als Handlungsanregung in der Landwirtschaft am Beispiel Klimaschutz*. Poster at Arbeitsforum Treibhausgasbilanzierung in der Landwirtschaft at LTZ Augustenberg 5-6 Oktober 2015 in Karlsruhe/Germany. Online available: http://www.ltz-bw.de/pb/,Lde/Startseite/Service/Nachlese.

Klepatzki, J., Zimmer, J., **Ellmer, F.**: *Treibhausgasminderung auf Sandböden: Einfluss differenzierter N-Düngung*. In Mitt. Ges. Pflanzenbauwiss. 27. (2015). 93-94.

Klepatzki, J., Vogel, H., **Ellmer, F.**: *Anpassungsstrategien in der Landwirtschaft*. In: Jahnke, J., Foos, E., Aenis, T. (Hrsg.): Klima-Bildungsgärten. Margraf Publishers, Weikersheim.

Klepatzki, J. (2015): *Treibhausgasminderung auf Sandböden: Einfluss differenzierter N-Düngung*. Presentation at workshop „THG-Bilanzierung in der Landwirtschaft", Landwirtschaftliches Technologiezentrum Augustenberg. October, 2015, Karlsruhe/Germany. http://www.ltz-bw.de/pb/,Lde/Startseite/Service/Nachlese.

Wolf, R.: *Treibhausgase vom Acker?*. Demonstration of gas measurements at „Potsdamer Tag der Wissenschaften", 9 May 2015 in Potsdam/Neues Palais/Germany.

Wolf, R., Zeitz, J.: *Auswirkungen von Wiedervernässung auf die Treibhausgas-Emissionen bewirtschafteter Niedermoore*. Presentation. AGROSNET-PhD Day, 10-11 March 2015, Berlin.

Wolf, R., Zeitz, J.: *Dynamische CO_2-Haubenmessung*. Poster. „Potsdamer Nacht der Wissenschaften", 9 May 2015, Potsdam.

Wolf, R., Zeitz, J.: *Effects of rewetting on greenhouse gas emissions of cultivated fens*. Poster Summer School Wien, 30/08-05/09 2015, Vienna/Austria.

Wolf, R., Zeitz, J.: *Auswirkungen von Wiedervernässung auf die Treibhausgas-Emissionen bewirtschafteter Niedermoore*. Poster, DBG-Tagung, 5-9 Sept 2015 in Munich/Germany.

2014

Hansen, A., Holz, K., Karatay, Y.N.: *Wie geht und was kostet eigentlich Klimaschutz in der Landwirtschaft?* Poster and game at „Lange Nacht der Wissenschaften". 10 May 2014 in Berlin-Dahlem/Germany.

Karatay, Y.N., Meyer-Aurich, A.: *Contribution of normalised N-response functions to the assessment of regional comparative cost advantages of GHG mitigation in Brandenburg, Germany*. Presentation, TradeM Workshop, 24 Sept 2014, Vienna/Austria.

Klepatzki, J., Döring, T., Macholdt, J., **Ellmer, F.**: *Comparing the reliability of maize variety data from on-farm trials and experimental stations*. In: Journal für Kulturpflanzen, 66 (11):389-395. Eugen Ulmer, Stuttgart.

Klepatzki, J., Döring, T., Macholdt, J., **Ellmer, F.**: *On-Farm-Versuche zur Sortenprüfung bei landwirtschaftlichen Nutzpflanzen in Brandenburg*. In: Bachinger, J., Bloch, R., Fohrmann, R. Pfriem, R. (Hrsg.): Land- und Ernährungswirtschaft im Klimawandel. Oekom Verlag, München.

Klepatzki, J., **Ellmer, F.**: *Treibhausgasminderung auf Mineralböden: Potenziale in verschiedenen Nutzungssystemen*. In: Mitt. Ges. Pflanzenbauwiss. 26:34-35.

Klepatzki, J.: *Evaluation of maize varieties in a changing climate: on-farm vs. experimental stations*. Presentation at IFSA (International Farming System Association). April, 2014, Berlin/Germany.

Wolf, P., Holz, K.: *LandPaKT–Agricultural techniques: potentials and costs of greenhouse gas mitigation*. Presentation at FACCE MACSUR Mid-term Scientific Conference University of Sassari/Italy, April 3rd, 2014.

Wolf, R.: *Gase fangen in Brandenburger Mooren - wir kommen dem Klimawandel auf die Spur*. Presentation at Marie-Curie-Tag at Marie-Curie-Gymnasium. 13.11.2014 in Ludwigsfelde/Germany.

2013

Hansen, A., Wolf, P.: *Ziele und Konzept des Verbundprojektes LandPaKT*. Presentation at 2nd Conference „Möglichkeiten und Grenzen der Minderung von Treibhausgas-Emissionen aus der Landwirtschaft", 27-28 Aug 2013 in Münster/Germany.

Hansen, A., Holz, K., Karatay, Y.N.: *Wie geht und was kostet eigentlich Klimaschutz in der Landwirtschaft?*. Poster and game at „Lange Nacht der Wissenschaften“, 8 June 2013 in Berlin-Mitte/Germany.

Hansen, A., Holz, K., Prochnow, A., Herrmann, A., Zeitz, J., Kirschke, D., Ellmer, F., N.N.: *Landwirtschaftliche Verfahren - Potentiale und Kosten für die Treibhausgasminderung - Leibniz-Graduiertenschule LandPaKT*. (Poster) 6th Agrosnet-PhD-Day, May 16th 2013 in Berlin-Dahlem/Germany.

8 Safeguarding the Preservation of Results

According to the effective guidelines of good scientific practice at the Leibniz Association [15], the ATB and the Humboldt-Universität[16], project results were preferably published open-access (OA) (manuscripts in peer-reviewed open-access journals, and dissertations in OA repositories, for instance the HU-edoc publication server[17]). This report is made available from the Leibniz site[18]. Primary data are stored in the repositories of the project partners, according to their institutional standards.

The project website[19] has been hosted at the ATB and will remain online. It provides links to presentations that have not yet been published elsewhere. A Monica debugging tool is available online[20].

A cooperation agreement has been signed to formalize the continuation of soft skill education of ATB doctoral researchers between the Humboldt Graduate School at the Humboldt-Universität and ATB.

9 List of Press Releases and Media Reports

Hansen, A. (2016): *Assessing potentials and costs of greenhouse gas mitigation*. Abschnitt in ATB-Research Report 2014-2015:83. Online: https://www.atb-potsdam.de/fileadmin/docs/Jahresberichte/atb_jahresbericht_2014-2015_kl.pdf.

Senat der Bundesforschungsinstitute im Geschäftsbereich des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz (Hrsg.) (2013): *Auftakt der Leibniz Graduate School LandPaKT*. ForschungsReport Ernährung – Landwirtschaft – Verbraucherschutz FoRep 2/2013 (Heft 48) S. 49; https://www.bmel-forschung.de//fileadmin/SITE_MASTER/content/bilder/ForschungsReport/2013_2/FoRep_2-2013_final_web.pdf.

Der Präsident der HU (2013): *Auftakt: Leibniz Graduate School LandPaKT*, HUMBOLDT - Die Zeitung der Alma Mater Berolinensis, 17.10.2013, Jg. 58 S. 2; http://edoc.hu-berlin.de/series/hu-zeitung/58-1/PDF/1.pdf.

Bauernzeitung (2015): "Im Gespräch" - M. Rebhann 21. Woche, S. 20.

[15] https://www.leibniz-gemeinschaft.de/fileadmin/user_upload/downloads/Forschung/Leibniz_Association_GUIDELINES_Good_Scientific_Practice_2015.pdf
[16] https://gremien.hu-berlin.de/de/amb/2014/06/06_2014_20140130%20Beschlussversion%20Satzung%20Wissenschaftliches%20Fehlverhalten_DRUCK.pdf, https://www.cms.hu-berlin.de/de/dl/dataman/fdt-guidelines, https://www.cms.hu-berlin.de/de/dl/dataman/hu-fdt-policy
[17] https://edoc.hu-berlin.de/?locale-attribute=en
[18] https://www.leibniz-gemeinschaft.de/ueber-uns/leibniz-wettbewerb/projekte-2013/2013-foerderlinie-4/
[19] http://www.landpakt.atb-potsdam.de
[20] https://github.com/ATB-Potsdam