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MODELLING THE IMPACT OF AGRICULTURE ON THE GREENHOUSE EFFECT ON REGIONAL SCALE

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ABSTRACT. Many models on the contribution of agriculture to the greenhouse effect exist. Yet there is a lack of a complete picture of the interactions between land use and carbon emissions in Europe especially from the economic point of view.

Key words: agriculture, greenhouse gas emissions, sink enhancement, modelling

Introduction

In the light of the greenhouse effect being significantly boosted by anthropogenic emissions wherein agriculture contributes a share of approximately ten percent in Europe, there is a strong need to include this section in mitigation strategies, as well. From the so-called "Six Kyoto Gases", identified to be the most significant ones to climate change, carbon dioxide, methane, and nitrous oxide originate with shares of 3%, 42% and over 50% from agriculture.

Agriculture takes an outstanding position as it is not only a source of emissions but might act as a sink for greenhouse gases, although biological processes that are benefited from are difficult to influence and control. Besides, this technical problem mitigation options have to be accepted by farmers which means measures must pay out economically, especially in the long run as such enforcing a sustainable land use.

According to the Kyoto Protocol Article 3.4 each party should provide "data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years" (**Kyoto Protocol...** 1997). Until the year 2007 the European Union has to decide if to include carbon sinks in their inventory and by doing so there would be the obligation to deliver a year wise estimate of the change in carbon stocks. This estimate must be comprehensible and the methods clear and scientifically verifiable.

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Modelling is the single passable way to account for these emissions at least on a regional scale since a quantification by measuring over larger areas is not realisable. The decision for or against a certain model takes a key position as neither economic nor ecological models alone are able to provide an integrated estimate of the economic and ecological effects while linking both types of models combines their advantages.

With the help of such economic-ecological agricultural models, different production intensities, feeding strategies, as well as barn and storage systems for liquid manure can be modelled under consideration of various mechanisation techniques, and the respective impact of abatement strategies on emissions can be quantified. Furthermore, model calculations can be used for the appraisal of technical and political mitigation strategies with regard to their reduction potential and abatement cost on farm level.

This paper will present a small selection of models presently in use thereby classifying the **E**conomic **F**arm **E**mission **M**odel (**EFEM**) of the University of Hohenheim. **EFEM** results of former simulations are drawn to illustrate their kind and the functioning of **EFEM** discussing the problems arising on the way to them. A short introduction of the application of **EFEM** within the **I**ntegrated **S**ink **E**nhancement **A**ssessment (**INSEA**) project financed by the Commission of the European Union will be given.

Model types and examples

The dilemma in any modelling of spacial emissions is between the limited data availability or data processing facilities and the aggregation error. The direction of summarising or dividing data from a larger to smaller scale respectively vice versa suggests a general division of economic models for the modelling of greenhouse gas emissions in agriculture into top-down and bottom-up models. The first mentioned are based upon the method of downscaling, e.g. from a whole sector to a smaller spacial aggregation being of the type partial or general equilibrium models. The bottom-up approach takes farms or homogeneous grouped farms as starting point arising thus the question of how to extrapolate these farms and guarantee for the consistency between data of different scales (**Kleinhanss** et **al.** 2003). While equilibrium models are of the type econometric models thus being dependent on time series or generally speaking on past information, a second type is very common among economic models which are the optimisation models with the subcategories of linear and non-linear models. These are more flexible in terms of modelling of alternative productions and new mitigation options since they not necessarily require past information. Advantageous to optimisation models further is the easy way to include restrictions on farm level rearing for example from the numerous decrees and regulations relevant in agricultural policy in the European Union. Besides, a second characteristic of the agricultural sector being the low variation in prices gives the point again to optimisation models. Unfortunately, linear programming models tend to deliver jumping results and cannot include economies of scale and scope as they are based on linear functions.

For the modelling of greenhouse gas emissions within the European Union the **C**ommon **A**gricultural **P**olicy **R**egional **I**mpact (**CAPRI**) model is quite well known. Originally it was designed to analyse the regional impact of the **C**ommon **A**gricultural **P**olicy (CAP). This top-down model faced the challenge to develop a modelling system that could combine deep regionalisation with complete coverage of the agricultural sector in the European Union with two interacting modules which are a supply and a market module. The first one is designed to represent production activities on a regional scale and is guided by frame data (market clearing prices) from the market module which again is based on supply quantities from the regional models. Subsequently, agricultural prices are endogenous to the model. The division into two modules was indispensable for reasons of computational limitations when considering 200 regions and some 50 products. An iterative process between the supply and the market component achieves a comparative static equilibrium. The supply module is optimised with functions of the type positive mathematic programming which in comparison to linear programming goes in hand with a smoother more realistic response to changes in exogenous parameters.

The University of Hohenheim model **EFEM** in contrast is of the linear programming type and up to now has only a very limited regional coverage but considers agriculture in a very disaggregated way with a lot of restrictions being included (approximately 1400 binding restrictions). It is possible to distinguish between arable and grassland farming including the necessary mechanisation. Animal husbandry with a highly disaggregated feeding module, the use of manure and a farm nitrogen balance are represented. **EFEM** is combined with an ecological model in order to benefit from the advantages of ecological models which are to be seen in the representation of relevant biological processes going on in soils thus being able to produce site-specific estimations for emissions in relation to management and natural conditions. Up to now there is the linkage with the **D**e-**N**itrification **D**e-**C**omposition (**DNDC**) model which stands out by a very good representation of nitrous oxide emissions.

The high disaggregation and the infeasibility to estimate the emissions of all farms calls upon a way to aggregate or extrapolate farms. There are two principal procedures: 1) take an entire region as one grouped farm, or 2) extrapolate the results of single farms (**Kazenwadel** and **Doluschitz** 1998). **CAPRI** took the first way and models in the European Union administrative regions as one farm with the regional numbers for livestock, hectares, fertiliser etc. as consistency frame. The **EFEM** model in contrast allows for a more detailed consideration of emissions according to farm type and in smaller spatial units. Typical farms according to farm type are selected in a preparatory step for every region of interest. With a module of the linear programming type a weighing factor is calculated which corresponds to the number of farms necessary to represent the region as a whole, i.e. the farms capacities multiplied by the extrapolation factor must fit regional data although smaller deviations have to be permitted. These deviations are conferred to the farm's capacities which are beforehand weighed by their standard gross margins to guarantee for an adequate representation of the most important capacities in regard to the share hold in the total gross margin of the farm.

Agricultural carbon sinks

Carbon dioxide is the major gas of the natural and anthropogenic greenhouse effect but is needed by plants for their growth. It is bound in the lithosphere, in oceans and in the biosphere. For the time being, the only technically feasible measure for the enhancement of carbon sinks is the enrichment of the biosphere. In the **EU-15** countries the potential is estimated at approximately seven to ten percent of the anthropogenic CO_2 emissions (**Freibauer** 2003). Among mitigation options are frequently mentioned the conversion of agricultural to forest land or from cropland to grassland. Inherent to all mitigation options that aim at an increase of the biospheric carbon stock is the problem of non-permanence and the characteristic to agricultural land which is the high variability of the sink function per year depending largely on the weather. With a change in land use former sequestered carbon can be freed and turned back into the atmosphere easily. Especially undermining at the carbon stock is a shift from forest land to cropland and from cropland to grassland. To trust in mitigation options in terms of management change from conventional to zero-tillage or a permanent plant coverage of the soil is subject to the same problems but could be economically more valuable which still stands out to be verified in the case of Europe. Nevertheless, at least short-term stock increases can be recognised after a change in the management.

With INSEA the Commission of the European Union finances within the Sixth Framework Program a project that aims at developing an analytical tool to assess economic and environmental effects for enhancing carbon sinks on agricultural and forest lands. Finally, there will be delivered marginal abatement cost curves representing the costs of abatement per unit of CO_2-equivalent. The University of Hohenheim contributes with the EFEM model to the economic component.

Results

For the huge quantity and variety of already existing results only some exemplary ones are depicted here. In comparisons of the impact of emissions on the greenhouse effect their **G**lobal **W**arming **P**otential (**GWP**) is applied and in accordance with the majority of scientific works on this topic the **GWP 100** that means the Global Warming Potential within a 100 year period is taken as basis here.

According to the extrapolation procedure described in this paper the farm types listed in Table 1 were selected for the Baden-Württemberg region “Rhein-Bodensee”.

With EFEM in combination with DNDC it is possible to estimate site-specific emissions according to the farm type of which the estimated emissions of a forage growing cattle farm and an intensive feedstock farm with pigs are shown in Table 2.

In the former chapter the calculation of marginal abatement cost curves in agriculture and forestry was mentioned as an important outcome. Results in this case already exist and are delivered by several authors that relied on different model types but nevertheless came to estimate similar costs. Marginal abatement costs are calculated as the loss in the total gross margin when a certain percentage of emissions have to be omitted.

Perez estimated with the **CAPRI** model marginal abatement costs for two scenarios: 1) without a tradable permit system and 2) with a tradable permit system (**Perez** and **Britz** 2003). The results of the simulation without a permit trading system are illustrated in Table 3 for Germany and are compared to the **EFEM** results for Baden-Württemberg. A close comparison of results yet is not available because the regional coverage differs so the numbers shown are just exemplary ones.

Table 1

Selected types of farms of the Baden-Württemberg region "Rhein-Bodensee" (Schäfer et al. in press)
Wybrane typy gospodarstw z regionu Badenii-Wirtembergii „Ren-Jezioro Bodeńskie" (Schäfer i in. w druku)

	Intensive livestock – poultry Chów intensywny – drób	Intensive livestock – pigs Chów intensywny – trzoda	Forage growing – cattle Chów bydła	Forage growing – sheep Chów owiec	Permanent crops Uprawy trwałe	Regional capacity Zdolność regionalna
Crop land (ha) Grunty orne (ha)	80.0	80.0	21.0	–	3.0	123 539
Permanent pasture (ha) Pastwiska trwałe (ha)	–	–	45.4	78.0	–	48 554
Sugar beet (ha) Buraki cukrowe (ha)	1.3	1.3	–	–		1 512
Potatoes (ha) Ziemniaki (ha)	–	–	–	–	0.5	1 658
Male cattle (heads) Bydło męskie (szt.)	–	–	19.0	–		20 289
Dairy cows (heads) Krowy mleczne (szt.)	–	–	30.0	–		32 109
Sheep (heads) Owce (szt.)	–	–	–	700.0		36 100
Pigs for fattening (heads) Trzoda na tucz (szt.)	–	150.0	–	–		53 884
Breeding pigs (heads) Trzoda hodowlana (szt.)	–	35.2	–	–		12 660
Laying hens (heads) Kury nioski (szt.)	396.3	–	–	–		310 731
Extrapolation factor Czynnik ekstrapolujący	784.2	359.2	1 070.3	51.6	3 197.0	

Table 2

Emissions in the Baden-Württemberg region "Rhein-Bodensee" according to farm type (Schäfer et al. in press)
Emisja w regionie Badenii-Wirtembergii „Ren-Jezioro Bodeńskie" według typu gospodarstwa (Schäfer i in. w druku)

	Intensive feed stock – swine Tucz intensywny trzody	Forage growing – cattle Chów bydła
Gross margin (EUR) Marża brutto (EUR)	79 425	77 851
NH_3-N emission (kg) Emisja NH_3-N (kg)	1 238	1 829
N_2O total (kg) N_2O ogółem (kg)	615	302
CO_2 total (kg) CO_2 ogółem (kg)	120 751	50 050
CH_4 total (kg) CH_4 ogółem (kg)	1 260	9 303
ruminal (%) przeżuwanie (%)	16	80
storage (%) magazynowanie (%)	84	20
GHG farm emission (t) Emisja GHG w rolnictwie (t)	338	339

Table 3

Marginal abatement costs for CO_2-equivalents in agriculture (EUR/t) (based upon data from Schäfer et al. in press, Perez and Britz 2003)
Zmniejszające się koszty marginalne dla ekwiwalentu CO_2 w rolnictwie (EUR/t) (na podstawie danych Schäfera i in. w druku, Pereza i Britza 2003)

Quota Udział (%)	Intensive feed stock – swine Tucz intensywny trzody	Forage growing – cattle Chów bydła	Baden-Würrtemberg average Przeciętna dla Badenii-Wirtembergii	Germany Niemcy
–4.7				53.5[1]
–10.0	35.1	51.3	44.5	
–15.0	59.0	111.2	88.4	
–20.0	78.4	135.3	108.2	

[1]Calculated by the CAPRI-model.
[1]Obliczone modelem CAPRI.

Discussion

Models as briefly introduced in the second chapter vary a lot in their structure and scope and the theoretic background they are based upon. Although ecological models can give quite a clear picture of development processes of greenhouse gases thereby considering a vast range of biological mechanisms they do not provide any economic factors. For achieving a larger spatial coverage, these are dependent on land use maps, soil maps, and climatic maps. Other input data can be delivered by economic models which represent management decisions under changed economic and/or political conditions including the effects on the farm structure. Economically optimal intensities of fertilisation and other input use, the optimal crops being grown and the optimal combination of production factors are calculated. A general statement if top-down or bottom-up emission models are better cannot be given because many criteria are to be regarded, but above all the client or the user decides what is important for him, i.e. if he needs a detailed picture of a smaller region or if he prefers an overall picture including trade into the modelling.

In terms of greenhouse gas emissions models and linked models are currently available but yet these do not consider carbon stocks and the economics of mitigation options in regard to carbon dioxide. With the INSEA project a comprehensive picture about the preferencability of mitigation options inclusive land use change will be produced. The estimated marginal abatement costs have to be compared to the costs in other sectors and impacts on other aspects should not be neglected like biodiversity and maintenance of cultural landscapes just to point to some examples.

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MODELOWANIE WPŁYWU ROLNICTWA NA EFEKT CIEPLARNIANY
W SKALI REGIONALNEJ

S t r e s z c z e n i e

Istnieje wiele modeli opisujących wpływ rolnictwa na powstawanie efektu cieplarnianego, jednakże do tej pory nie powstało w Europie kompletne opracowanie wyjaśniające interakcje zachodzące pomiędzy użytkowaniem ziemi rolniczej a emisją dwutlenku węgla. Ponadto nie przedstawiono dotychczas ekonomicznych skutków problemu. Artykuł prezentuje wybrane modele aktualnie stosowane do analizy badanego zjawiska.