Towards an Analytical Capacity in Costing of Abatement Options for Forestry and Agricultural Carbon sinks

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1 Introduction

In December 2001 EuroCARE was assigned to review existing models and recommend the most suitable analysis methods and modelling approaches with respect to carbon sinks in agriculture and forestry. According to the schedule the final report is now presented.

2 Scope of the study

The Kyoto commitments of December 1997 and the results reached at the Climate Conferences in Bonn (the 6^{th} Conference of the Parties – COP 6) in July and in Marakesh (COP 7) in November 2001 provide the background of the study. The Kyoto Protocol allows for the anthropogenic enhancement of carbon sinks in agriculture and forestry to comply with commitments. Due to the absorption potential of agriculture and forestry it is expected that policies in this field will contribute to a certain extent to achieving the reduction objective of the EU.

The overall objective of this study is a proposal to the EU on the development of analytical and model-based instruments for the analysis of abatement costs in agriculture and forestry taking account of carbon sinks and non-CO_2 greenhouse gases. In more detail the study will pursue the following sub-ordinate objectives:

- review existing economic sector models in agriculture and forestry with respect to their suitability for the quantification and modelling of carbon sinks, and the derivation of marginal cost curves for the abatement of greenhouse gas emissions via carbon sinks enhancement
- propose options to the European Commission with the objective of identifying those model approaches which are particularly suitable for achieving the objective, and recommend further model developments to largely meet the demands from policy advice.

On the European level extensive studies have been carried out and results were published, such as the report of Working Group 7 'Agriculture', or the extensive report of the ECCP of June 2001 as well as a number of studies from natural sciences. This study does only consider models, which particularly emphasise policy options for carbon sink strategies and abatement potentials for non-CO_2 greenhouse gases in agricultural soils (C-accumulation and N_2O emissions), biomass, enteric methane emissions and manure management.

If models do take account of further political and technical approaches to emission reduction, then this has to be taken into account as well. However, measures which cannot be controlled or influenced by political actors, will not be considered in this study. These are, for example, measures regarding the optimal feeding of ruminants, feeding additives, temperature control, cleaning of animal housing facilities, grassland management, optimal use of machinery, as well as mitigation measures for NH_3 emissions which affect the climate indirectly.

3 Methodology

The study is based on a literature review and a detailed assessment of existing model approaches provided they are already or can possibly be used for policy advice in the European Union and/or permit the site specific connection of economic and ecological parameters with emissions of greenhouse gases on the farm and forestry level.

The models in question are presented in an overview fashion. They are listed according to important economic requirements, a selection of relevant ecological parameters, and criteria that reflect distribution effects. Of these assessment indicators the existing models have to fulfil the so-called essential criteria in any case. The resulting models are in principle suitable for the analysis and modelling of policy options for carbon sinks. In the next project phase the pre-selected models will be investigated with respect to: a) options for a detailed further development, and b) starting points for linking the models with upstream and downstream models.

4 Evaluation framework and indicators

From a scientific point of view, forests and agricultural land use as well as management practices are considered to offer a promising opportunity for the mitigation of greenhouse gas emissions. In order to derive the economic and ecological effects of the absorption of atmospheric carbon and mitigation strategies for greenhouse gases these need to be integrated into suitable models. Generally measures such as afforestation, biomass for energy, extensification, conventional land use practices, and other mitigation strategies compete for available land resources. Consequently, model approaches should consider both agriculture and forestry simultaneously. For this reason policy approaches with respect to carbon sinks have to consider carbon accumulation through fixation into soils, plants, and trees adequately since they represent a considerable carbon sink. It has to be taken into account, though, that carbon accumulation activities exhibit saturation where the biological capacity is reached. In this case costs to maintain the carbon sink after saturation may be incurred.

In the United States research is not only concerned with CO_2 abatement costs and the effect of financial incentives for CO_2 reduction, but it is also concerned with the effect of policy measures to enhance CO_2 sinks on the asset value of land resources. High financial incentives lead to an increase in the value of those soils and trees which have a high potential for a CO2 carbon sink, and which will reach their carbon carrying capacity only after a number of years. Extensive resource use or even a complete renunciation from production can generate yields which potentially lead to higher land rents and value increases such that investors from outside agriculture may be attracted. If such effects are also relevant for the EU, then movements of asset values should be taken into account.

In addition to the predominant criterion of CO_2 abatement costs the models have to fulfil a number of essential evaluation criteria.

4.1 Essential evaluation criteria

(1) **Production coverage**: The models should comprise the main agricultural and forestry production activities. The agricultural sector models have to include all significant traditional products. With respect to plant production at least the main field crops, root crops, oil seeds and protein plants need to be covered. Furthermore the most important animal husbandry activities and processing industries should be considered. The forestry sector models have distinguished different age groups, taking dynamic growth processes into account. An explicit interaction between types of both models would be desirable.

(2) **Regional coverage**: A differentiated regional representation of the 15 EU-Member States is essential. Further, these models should have at least the potential to include the main candidate countries. The data at the Member State or sub-region level have to be consistent with official EU-data. It is desirable to connect these models with global models to incorporate the impact of EU policies on carbon sinks on world market prices and feedback from the world market. This is also true for forestry models and their compatibility with global trade models for forestry products. This target is ambitious, but, in the long run desirable.

(3) **Economic steering mechanism**: The models should be based on microeconomic principles reflecting decisions of economic agents and the working of factor and commodity markets.

This is a precondition for the analysis of the impacts of alternative agricultural and environmental policy scenarios.

(4) **Trade offs with environmental quality**: A great number of policy options for CO_2 sinks can have positive as well as negative effects on the environment such as interactions between no-tillage land use systems and plant protection measures, fertilisation intensity and nitrate leaching, manure management practices and ammonia emissions, set-aside and nature conservation etc. It would be counterproductive to consider all interactions between abatement strategies and environmental quality goals as essential criteria, however, the most important of them should be recognised.

(5) **Site specific effects**: Carbon accumulation and nitrous oxide emissions are the main starting points for climate policy in agriculture and forestry. The effectiveness of both is mainly site-specific. The carbon accumulation and GHG mitigation potential depend on the actual carbon and nitrogen content of the soil as well as local and site specific factors, particularly soil type, precipitation, land use, rotation, soil preparation techniques and others. For example, the dynamics of carbon accumulation and nitrous oxide emissions differs between sandy soils and organic soils. In case of a land use change from arable land to permanent grassland carbon accumulation can exceed several hundreds of tons per ha easily, and vice versa ploughing of permanent grassland on organic soil can release up to 20 kg of N_2O per ha every year, which is more than 6 t CO_2 equivalent and 4-5 times more than from mineral soils. The most relevant location factors are soil type and climate, whereas decisive management factors are nitrogen input, soil preparation techniques, land use change and rotation. It follows for modelling that a regional differentiation following political borderlines is not appropriate. Within those regional borders a site specific spatial resolution is required. Hence, models should include either consecutively connected sub-models for each location factor, or all location factors should be integrated into one site-specific sub-model. Where applicable these can be linked with a Geographical Information System.

(6) **Allocation and distribution effects**: The models should be able to quantify the impacts of policy options on environmental objectives, especially the estimation of marginal abatement cost curves. Additional information on other political objectives as income distribution and employment would be preferable.

(7) **Reputation and status of application of the model**: Furthermore, an important aspect in the modelling assessment has to be the question of development time and costs. The development of an entire new modelling approach taking account of all essential indicators was not considered in this study. Data collection, calibration etc., would require an excessive input of labour and time. Therefore, the experiences with model applications, model reputation, plausibility concerns and a clear model structure do play an important role in the model assessment process.

4.2 Additional criteria

With respect to the intended purpose of the analytical tools required by the European Commission the following criteria are of less importance. Therefore, they are only listed and not discussed in detail:

- integration of ammonium as an indirect climate affecting gas
- interdependencies between other environmental indicators, in particular erosion
- effects on the ozone layer
- effects of eutrophication and acidification
- effects on human health

- effects on biodiversity.

4.3 Concluding remarks

With respect to the objective of the study seven essential evaluation criteria were identified which serve as a basis for the assessment of different models. The criteria cover agricultural and forestry production activities, regional aspects, economic steering mechanisms for resource allocation and the determination of abatement costs, interdependencies with other environmental goals, site specific disaggregation according to soil characteristics, climate indicators, allocative and distributive effects, as well as the model's reputation and acceptance as a tool for policy advice.

5 Overview of existing models in agriculture

In the Interim Report a comprehensive overview of all existing models was given. After a first preselection only those models are presented in detail in the Final Report, that assist in finding solutions to the costs and potentials of carbon sinks in agriculture and forestry. The applicability of these models is analysed in more detail below. Less suitable models are described in Appendix 1.

5.1 Carbon sink modelling systems in the U.S.

The agricultural sector and greenhouse gas mitigation model ASMGHG:

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SCHNEIDER, U.A. and MCCARL, B.A. (2000): The Agricultural Sector and Greenhouse Gas Mitigation Model (ASMGHG). In: http://ageco.tamu.edu/faculty/mccarl/papers/asmghg_2000.pdf

SCHNEIDER, U.A. (2000): Agricultural Sector Analysis on Greenhouse Gas Emission Mitigation in the United States. Dissertation from Texas A&M University.

WILLIAMS, J.R., C.A. JONES and P.T. DYKE (1993): EPIC –Erosion Productivity Impact Calculator. In: ENGEL, T., B. KLÖCKING, E. PRIESACK und T. SCHAAF (HRSG.): Simulationsmodelle zur Stickstoffdynamik. Schriftenreihe Agrarinformatik, Band 25, Ulmer Verlag Stuttgart.

In the United States modelling systems for carbon sinks and abatement strategies are comparatively well developed. The models of the working group of McCarl, Texas A&M University, have been used in policy advice. The overall objective of ASMGHG is to analyse the potential of U.S. agriculture to mitigate greenhouse gas emissions (GHGE). For this, the existing agricultural sector model (ASM) was chosen as a basis. It was augmented by tools to determine the emission or absorption of carbon dioxide, methane, and nitrous oxide to form the ASMGHG model. ASMGHG was also expanded to include forestry possibilities for carbon production by including data on land diversion, carbon production and economic value of forest products as generated from a forestry sector model FASOM. This model approach and the integration of results from various other models on different levels of scale can be useful for the design of a comparative model in the EU. In the following the individual model parts are described in more detail:

Base model ASM

ASM is a programming model of the U.S. agricultural sector in which prices are endogenous. It covers the production, consumption, and trade of 63 regions in the U.S. ASM integrates 22 traditional crops, 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. ASM simulates the market and trade equilibrium of agricultural markets in the U.S. and its main trade partners. The model outputs are equilibrium prices, quantities of supply and demand, resource use, and social welfare impacts. The solution values have to be interpreted as intermediate-run equilibrium results.

Model development to analyse GHGE mitigation options

In a first step potential mitigation options are defined. These refer to all relevant greenhouse gas emissions from plant and livestock production, and from basic processing.

GHGE and potential mitigation options from livestock production are accounted for by including secondary data from the U.S. Environmental Protection Agency (EPA) and IPCC. This part of the model development is not described any further because on the one hand, the integration of GHGE from livestock production activities is not particularly new, and on the other hand, the focus of this study is more on carbon sinks in agriculture and forestry.

Of great interest from a methodological point of view is the integration of GHGE from plant production activities. A plant growth simulation model (EPIC = Erosion Productivity Impact Calculator) is employed to derive specific regional emission data. EPIC was developed in the United States in the early 80s. It has originally served to identify the effects of different crop management strategies on crop productivity, soil erosion, and on the water household. In the meantime it became possible to simulate the effect of various crop management strategies on soil organic matter content, nitrous oxide emissions through denitrification or air volatilisation. Other important environmental parameters such as soil erosion and nutrient leaching (N and P) can be determined with the help of EPIC as well. Normally, the model is applied to simulations on the plot level, whereby soil, crop management practices and weather are assumed to be homogenous.

Within ASMGHG the EPIC simulation model is used for two important sources of emissions and absorption. On the one hand this is the effect of altered fertilisation practices on mitigation options is simulated and tested. It is not only the N_2O emissions through fertilisation, which are determined, but also the carbon sequestration rates caused by a changing fertilisation management regime. On the other hand, the carbon sequestration rates under different soil management practices (conventional tillage, minimum tillage, and no tillage) are analysed. The spatial representation in EPIC corresponds to the 63 regions of the agricultural sector model, whereby ten crops and five soil types are simulated. The GHGE resulting from the EPIC simulations are taken as the emission factors for the agricultural sector model. SCHNEIDER (2000) gives a detailed description of the modelling approach and in particular the integration of the simulation results from EPIC into ASMGHG. He also specifies on the data flow between the models.

Another point, which is of interest from a methodological point of view, is the integration of the Forest and Agricultural Sector Optimisation Model (FASOM), which is a dynamic non-linear programming model of the forest and agricultural sectors in the United States.

With ASMGHG marginal abatement cost curves for GHGE have been identified for the U.S. agricultural and forestry sector. It is not only single strategies but also the portfolio of potential strategies, which are tested against each other. Thereby the comparative advantage of single mitigation strategies under different farmer-received carbon prices together with the corresponding mitigation potential can be derived.

Evaluation

ASMGHG principally meets the main essential requirements listed in chapter 5 with respect to U.S. agriculture and forestry. The use of different types of models on different levels of scale as well as the integrative combination of results from individual models and an agricultural sector model represents a methodology which is promising for the further modelling of mitigation strategies for carbon sinks in agriculture and forestry. A direct transfer of the approach to the EU would be difficult because of the required large demand for differentiated and comparable data for all EU-Member States. The gathering of input data and the adaptation of the production matrix, factor endowments and the input parameters of the ecological modules of the model would already require a high labour input. Therefore, a direct transfer of the model to the specific conditions within the EU can be singled out. From this it follows that a further development of already existing models from within the EU that were widely applied to policy analysis and advice are more appropriate for the integration of carbon sink strategies. Still, it has to be mentioned that the models of the McCarl working group have in fact been applied to model policy options for carbon sinks in the United States, and they are highly accepted as a tool for policy support.

5.2 Relevant modelling systems for the European Union

5.2.1 Greenhouse Gas Emission Control Strategies (GECS)

References

CAPROS, P. et al. (1997): The GEM-E3 model: Reference Manual.
STRENGERS, B.J. (2001): The Agricultural Economy Model in IMAGE 2.2. RIVM Report 481508015, Bilthoven, Netherlands.
THE GECS PROJECT (2002): Project description In: http://www.upmf-grenoble.fr/iepe/GECS/index.html
THE IMAGE 2.2 MODEL (2002): Description of the IMAGE 2.2 Model. In: http://www.rivm.nl/image/
TINKER, B. et al. (2000): Report of the third session of the IMAGE Advisory Board. RIVM Report 481508014, Bilthoven, Netherlands.

Under the Fifth Framework Programme for Research the GECS project is developed with several partners[1]. The goal of the GECS project is to develop global (world) scenarios in order to analyse the impacts of Post-Kyoto policies under flexibility mechanisms for emission reduction, including options to reduce emissions resulting from land use change and for strengthening carbon sinks.

The research component of the project aims at enhancing and using international energy and economy models already developed in the context of preceding Framework Programmes, in order to fully analyse the consequences of different patterns of international commitments, agreements and rules for the control of greenhouse gas emissions to the 2030 horizon.

The GECS project develops synergies between the POLES and GEM-E3 models.

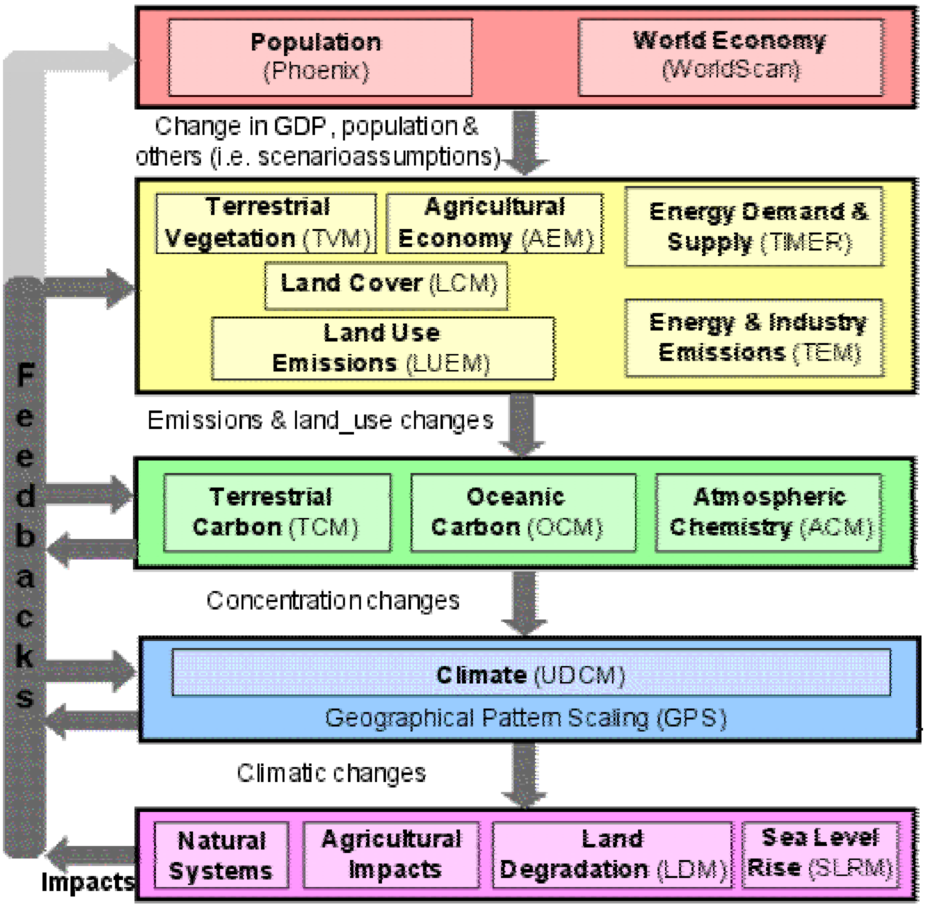
The POLES model is a partial equilibrium model used for the illustration of the world energy sector. Together with the GEM-E3 (**G**eneral **E**quilibrium **M**odel for **E**nergy-**E**conomy-**E**nvironment), it is to be used for the analysis of policy measures with regard to climate protection. The GEM-E3 is an applied general equilibrium model for EU member countries. GEM-E3 considers 18 sectors with agriculture being regarded as an independent sector. In the context of the GECS project, further

[1] ICCS-NTUA Athens, JRC-IPTS Seville, CES-KUL Leuven, ZEW Mannheim, Federal Planning Bureau Brussels, CIRAD-ECOPOL Paris, RIVM Bilthoven

modules shall be used for the assessment of greenhouse gas emissions that are not energy related, and their respective prevention cost. One example is the IMAGE model conceived at RIVM (National Institute of Public Health and the Environment, Bilthoven, The Netherlands).

IMAGE is a model component within GECS. An overview of the different submodels is shown in the following figure.

Model framework of IMAGE 2.2



Source: National Institute of Public Health and Environment

The IMAGE 2.2 model distinguishes between 19 world regions. In this context, Europe is subdivided into OECD Europe and Eastern Europe.

Within this compound model, several modules may be of special importance for the determination of forestry and agricultural carbon sinks:

1. Terrestrial Vegetation (TVM)
2. Land Cover (LCM)
3. Land Use Emissions (LUEM)
4. Terrestrial Carbon (TCM)
5. Agricultural Economy Model (AEM)

Models 1 to 4 actually have a spatial solution of 0.5° x 0.5° grids (approximately 50 km x 50 km).

The Agricultural Economy Model (AEM) takes into account twelve different food products, seven of which are of plant origin with the other five products coming from animal production.

The core of the AEM consists of regional utility functions; these yield a utility value for a given diet composed of basic and affluent products. The maximum utility is achieved when the demand equals the so-called 'preference level'. Preference levels are the daily per capita consumption in the case of no constraint on production for a given income level.

The overall shape and steepness of the utility function is determined by the values of preference levels and weighting constants indicating the eagerness to consume food products at their preference level. The weighting constants and preference levels have fixed values for each region; this is based on an historical analysis, as described in detail in Strengers (2001). In some scenarios, preference levels decrease after 1995.

The AEM optimizes the utility function in terms of land 'budgets', which are expressed in m^2 per capita. The maximum budget is the amount of land needed to produce the preferred diet (i.e., production equals preference levels for both basic and affluent products). The actual budget is a function of income, land-use intensity, income elasticities and the 'half-life' parameter.

Food products are valued by using land-use intensities as surrogates of food prices. Land-use intensities are equal to the amount of land needed to produce 1 Kcal of the product under consideration. The half-life determines (in combination with the income elasticities) the rate at which the actual budget approaches the maximum budget with rising income.

The Agri-Pol model is used as a further agricultural economic model in the GECS project. Agri-Pol was developed and applied by CIRAD-Amis. It is a non-linear optimisation model that takes into account different production technologies and production intensities as well as farmers' attitudes concerning risk. The model optimises the net revenue of the agricultural sector minimising the risk associated of agricultural production, subject to input constraints such as land, labour and capital. The starting point of the model are the results obtained from IMAGE with respect to land use and expected production. With the help of Agri-Pol marginal abatement cost curves for carbon in the 17 IMAGE regions can be derived. Furthermore, results from Agri-Pol are used as inputs in the POLES model. Agri-Pol takes eight different activities into account, namely dairy livestock, non-dairy livestock, rice, cereals, oil seeds, and as an aggregate pulses, roots and tubers, pasture and forest. Altogether 40 regions are considered, of which each European country is considered to be one.

Evaluation

The GEM-E3 which is used in the GECS project actually images the European agricultural sector on a level too highly aggregated to allow for an assessment of abatement options. For the development of an econometric model like GEM-E3, the availability of appropriate data stemming from long-term time series is an indispensable prerequisite. However, the availability of such data is not ensured, especially on the background of changes in EU agricultural policies expected for the next few years to come.

The AEM model which is utilised in the IMAGE modelling system is interesting from a methodology point of view, yet under economic aspects it appears to be unsuitable for modelling the agricultural sector. For example, the derived term 'land-use intensity” stands as a proxy for product prices and other important economic items. The Advisory Board of the IMAGE research team, which, in intermittent intervals, evaluates the project, has already identified the weak points of the AEM. The Advisory Board, which consists of international researchers from various disciplines as well as political decision makers, has by now defined the requirements for an economic model regarding the agricultural sector within IMAGE 2.2 compound model. According to this standard, the agriculture sector model that is to be integrated, shall be able to simultaneously simulate the production, trade and consumption of both energy and agricultural commodities. The economic model should also be able to simulate competition for land and water resources by agricultural, forestry, and bio-energy uses. A review of actual refinements within the available AEM has to be carried out, eventually touching the question whether it should be replaced by another model, and if so, which.

Currently, an evaluation of the Agri-Pol model turns out to be difficult, since no scientific publications on the model are available, yet. The brief description above is mainly based on a number of short papers which are made available on the GECS project homepage. However, these do only provide a very brief overview over the mathematical structure of the model, and do not specify the data input and the interaction of Agri-Pol with the other models in more detail. According to the researcher in charge of Agri-Pol, a detailed report on Agri-Pol will be made available as part of the final report of the GECS project in September of 2002.

5.2.2 Common Agricultural Policy Regional Impact Model (CAPRI-Model)

References

BRITZ W. (1998): A Synthetic Non-Spatial Multi-Commodity Model as Market Component for CAPRI, Capri Working Paper 98-07, University of Bonn

HECKELEI T. (1997): Positive Mathematical Programming: Review of the Standard Approach, Capri Working Paper 98-02, University of Bonn

HECKELEI T. & W. BRITZ (1999): Maximum Entropy Specification of PMP in CAPRI. CAPRI Working Paper 99-08, University of Bonn.

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The main objective of the CAPRI project (**C**ommon **A**gricultural **P**olicy **R**egional **I**mpact) was the development of an EU-wide economic modelling system designed to analyse the regional impacts of the Common Agricultural Policy (CAP). The project was co-financed by the EU under the FAIR program in the years 1997-1999. In order to achieve its objective, the project relied on the functionality of a European research network. Five main partners[2] were responsible for a specific cluster of Member States. They established research relationships with national sub-partners for data collection and interpretation of results.

A major part of the CAPRI project was to create an EU-wide comparable information base. The Capri database obeys the following principles:

- **Regional differentiation** of the European Union to 200 regional units (mostly according to NUTS II definition)
- **Production activity** based break-down of agricultural production
- **Consistency** between sector and regional aggregates, i.e. data match official EUROSTAT statistics including the Economic Accounts of Agriculture (EAA)
- **Comprehensiveness** complete coverage of product generation and input use according to the EAA, inclusion of activity levels, yields, input coefficients, prices, farm & market balances, economic performance, policy instruments and environmental indicators.

[2] The research teams involved are institutes in the field of agricultural economics from the Universities of Bonn, Valencia, Galway, Bologna, and Montpellier (plus Research Station Tänikon (Switzerland) and NILF, Oslo).

Currently, the database is complete for the years 1990-1995, an update to the year 2000 is under way and will be completed before June 2002. The CAPRI-model differentiates between 60 outputs and 35 inputs, covering the whole agricultural sector according to EAA definitions, and about 50 crop and animal production activities.

The output and input coefficients are consistent with sector output generation and input use. Use activities, which define so called 'farm balances" for each output and input, describe the fate of the outputs and input 'generation'. Output produced may be sold, added to stocks, fed, used as seed etc. Inputs may be bought, taken out of stocks or stem from intra-sector transactions, for example young animals may be produced by another production activity. In order to link the physical sphere with the EAA, national unit value prices are derived. They are residually defined by definitorial equations underlying the methodology of the EAA.

At national level, the project relies mainly on a database, which has been developed in close co-operation with EUROSTAT, which integrates different databases, technological information and expert knowledge, and covers longer time series for all EU-Member States. The REGIO domain of EUROSTAT represents the uniform regional data source, which suffers, however, from incompleteness and a partially insufficient level of differentiation. Completely missing is information on CAP measures at regional level.

The database also comprises a set of environmental indicators. Useful indicators at this stage of the CAPRI information system are defined by: (1) a direct link to the agricultural production system, (2) meaningful interpretation at CAPRI's current regional level of differentiation, i.e., the NUTS II level, and (3) being operational with respect to data availability. These definitions exclude indicators, which describe states of environmental problems at local level or with respect to ecological systems defined by specific regional boundaries (e.g. water catching, landscape). CAPRI, however, offers the chance to incorporate environmental indicators in a consistent and uniform manner across Europe relating to the regional agricultural production system. Based on these considerations the project implemented nutrient balances and gas emissions relevant for global climatic change for all regions in the system.

The GHGE is described by a Global Warming Potential (GWP) indicator. The GWP indicator in CAPRI shows the GWP/ha main crop area and covers two sources of emission:

- CO_2, CH_4 and N_2O from mineral fertiliser
- CH_4 from animal production

In order to calculate the GWP, the coefficients have to be defined for average production activities.. These coefficients are the gas output per ton fertiliser and the methane-output of each animal activity per stable place and year. The coefficients are combined with regional data: in the case of mineral fertiliser the gas output per ton is multiplied with the regional total use of mineral fertiliser which indirectly depends on the specific nutrient output from animal production in each region (see above). In the case of emissions from animal production, the regional fattening or rearing period is taken into account.

The production activity approach with physical input and output coefficients underlying CAPRI is well suited to specify the use of non-renewable energy. It allows, for example, to compare the use of energy per ton produced between conventional and environmentally friendly production alternatives.

From a methodological point of view, the modelling system combines deep regionalisation with complete coverage of the EU-agricultural sector. This set-up is necessary in order to analyse simultaneously the impacts of market and policy developments on agriculture in the individual regions as well as the feedback from the regions to EU and world markets.

Since market and activity specific policy instruments require a rather disaggregated modelling approach, a simultaneous system, which would optimise producer and consumer surplus for 200 regions and some 50 products, was computationally infeasible. Consequently, the model system is conceptually split-up into a supply and a market component. The supply module consists of individual programming models for about 200 NUTS II regions. The market module follows the tradition of multi-commodity models. Based on aggregated supply quantities from the regional models, the market model returns market-clearing prices. An iterative process between the supply and market component ultimately achieves a comparative static equilibrium.

The supply module consists of independent regional programming models, well-suited for a high degree of activity differentiation and the direct representation of relevant farm policy measures (e.g. premiums, set-aside obligations) and ensure simulation results consistent with general resource constraints. The objective functions maximise the aggregated gross value added including CAP premiums minus a quadratic cost function based on Positive Mathematical Programming (PMP).

'Positive Mathematical Programming' (PMP) - known since the late eighties but formally introduced to the scientific community of agricultural economists by HOWITT (1995) - allows to calibrate a programming model to observed data regarding activity levels and regional feed use.

The mechanism for the market module generally is based on the standard concept of multi-commodity models. Double log equations for supply and demand clear regional and international markets, driven by regional producer and consumer prices, which are, linked via price transmission functions to a uniform world market price. The parameters of the behavioural demand equations are not estimated, but instead calibrated under theoretical restrictions based on elasticity estimates taken from literature.

The non-spatial net-trade model is regionalised at EU-Member State level, Switzerland, Norway, and 'Rest-of-the-World' (ROW). Data, behavioural parameters and exogenous shifts for ROW stem to a large extent from WATSIM, a worldwide modelling system for trade in agricultural products. Supply for all other regions are fixed to the results of the regional supply models. Price transmission functions cover tariffs, including flexible levies depending on internal price floors, as well as marketing and processing costs.

The CAPRI-Modelling system has been tested in 1999/2000 and has received positive critical evaluations from modelling experts of the scientific community. First policy oriented applications comprised regional impacts analysis of Agenda 2000 scenarios. At present, the CAPRI-Modelling system is being updated and developed further by the same composition of project partners in a further EU-FAIR project (CAPSTRAT-project). Policy oriented impact analyses are in preparation for various CAP-reform scenarios.

The CAPRI project has been successful in developing a regionalised agricultural information system for the EU. A regular update of the database, partial methodological improvements as well as a systematic validation of the model are necessary. It is quite clear that this can only be achieved with the network approach, which ensures the in-depth knowledge of regional aspects of agricultural production and the access to national data sources.

Evaluation

CAPRI meets the essential requirements for the analysis and optimisation of greenhouse gas abatement and carbon sinks strategies for the EU-Member States, although only for agriculture. The model is sufficiently disaggregated with respect to production activities and regional differentiation, which is a prerequisite for an adequate incorporation of balances for greenhouse gases. The model is consistent with European Agricultural Statistics (Eurostat's database) and is founded on microeconomic principles and sophisticated econometric approaches. The forecasting and simulation reliability of the model has been tested in many applications, so that the model has gained reputation as a tool for policy impact analysis in both science and EU-administration.

The CAPRI-Model contains already now a set of environmental indicators, but at the present stage not for greenhouse gases. For the analysis of the impacts of greenhouse gas abatement and carbon sinks strategies it will be necessary to incorporate additional activities, policy instruments, greenhouse gas balances and indicator systems. The envisaged options to realise this amendment will be sketched in section 8.

Limitations of the CAPRI-Model with respect to the analysis of greenhouse gas abatement and carbon sinks strategies lie in the fact, that some issues and some policy measures have to be tackled site-specific or on the farm level. This is e.g. the case, when the specific soil conditions are relevant, or when the impacts of alternative farming practises have to be analysed. Therefore, the analytical potential of the CAPRI-Model has to be complemented by site-specific and farm-sample analyses (see section 8).

5.2.3 World Agricultural Trade Simulation Modelling System (WATSIM)

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MÖLLMANN, C. (2002):Handelsbeziehungen unter veränderten agrarpolitischen Rahmenbedingungen – Eine Untersuchung des Weltagrarhandels mit dem Modellsystem WATSIM. Dissertation. Bonn.

The WATSIM Modelling System is a non-spatial, comparative-static, synthetic, multi-regional, multi-product partial-equilibrium world trade model for agricultural raw and processed products. Its development was entrusted by the European Commission, with a view to provide a tool to carry out the following tasks:

- Collection, consistency check and analysis of data on world agricultural markets and on different world regions. The data used is obtained from different sources.
- Provision of medium term forecasts on agricultural world market developments.
- Simulation of the effects of policy changes on production, demand, prices and trade of agricultural products in a variety of world regions.

The simulation model consists of a number of regional sub-models, where production and demand (human consumption, feed use, industrial processing, seed use, other use and waste are modelled separately) depend linearly on domestic prices. International markets are cleared by adjusting world market prices. The adjusted world market prices are in turn linked to domestic prices by regional price transmission equations, allowing for both the PSE-concept of USDA and OECD and the tariffication system forced by the WTO. All non-price developments of supply and demand are captured by trend factors.

As mentioned above, data stem from various sources. Most of the data, however, are taken from the FAO (production, demand and trade figures from Supply and Utilisation Accounts and Trade Yearbook, policy parameters from the GATT-schedules), the USDA (supply, demand and income elasticities -SWOPSIM data base- and policy parameters) and the OECD (policy parameters).

In its current version the model covers 29 agricultural products, both crops and animal products, and the world is represented in the basic version by 9 regions, but the basic data system enables farther regional differentiation according to the type of problem. Both the regional and product aggregation level can be easily adjusted to the simulation needs.

Policy oriented simulations were done on the impacts of the EU's 1992 and Agenda 2000 CAP reforms and the GATT's Uruguay Round agreement on agriculture. In addition, liberalisation scenarios for the 'grandes cultures' were simulated. Main characteristics of the current version are presented in the following table:

Overview on the World Agricultural Trade Simulation (WATSIM) modelling system

Major objectives	Analysis of ex-post developments in markets and policy Medium- and long-term outlook projections Simulation of alternative scenarios: - Policy changes - Macroeconomic conditions - Availability of production resources
Major strength of the model	- Global coverage (9 regions plus rest of world) - Large set of commodities (29) - Symmetric structure (production and consumption) - Detailed representation of agricultural policies, macroeconomic variables and production resources
Country coverage	DATABASE: Globally single countries (>210) SIMULATION MODEL: - EU-15, Central and Eastern Europe, Russia, - China, Japan, Australia and New Zealand, - Canada, USA, Mercosur, - Rest of World Symmetric representation of all commodity markets in each region.
Market linkages	Densely filled cross price elasticity matrices for supply and both food and feed demand Livestock-feed relation through feed energy balance Input-output relations for oilseeds and milk sector Domestic to international markets through gross trade and price transmission
Type of the model	- Comparative-static, - (mainly) synthetic, - deterministic, - non-spatial in terms of global spot markets, spatial in terms of gross trade representation, - partial-equilibrium
Sources of market data	FAOSTAT, USDA PS&D, COMTRADE
Source of parameters	Elasticities: Various sources, including Tyers/Anderson, FAO, SWOPSIM, and others Feed energy requirement parameters (own estimations)

Exogenous variables and their data sources	MACROECONOMIC VARIABLES: - Population and urbanisation (UN), - per capita income (World Bank, IMF) PRODUCTION RESOURCES: - Land availability and - irrigation (FAO, World Bank) POLICY MEASURES: - Tariffs, - threshold prices, intervention prices, - restrictions on subsidised exports, - tariff rate quotas, - production quotas, - set-aside rates (OECD, GATT/WTO, EU Commission, various other sources)

Evaluation

The WATSIM-model is not suitable as a stand-alone model for the analysis of carbon sink policy options because it does not contain a differentiated activity based description of agricultural production systems. But it can be a useful instrument for modelling the impacts of abatement strategies of the EU on international trade and resulting impacts on agricultural income, consumer rent and general welfare in other world regions. Further, the international trade flows provide a basis for a rough calculation of the greenhouse gas impacts associated with international transport activities.

Besides WATSIM some other world models have to be considered. As far as other partial equilibrium models are concerned (e.g. IFPRI-model[3]), they have the same possibilities and limitations as WATSIM. Worldwide general equilibrium models (e.g. GTAP-model) have the advantage that they are able to analyse the impacts of adjustments in the agricultural sector on other sectors simultaneously. However, this advantage has to be contrasted with the disadvantage that this type of models work, at least at present, on a much higher level of aggregation, which limits an adequate specification of abatement scenarios. In conclusion: The main advantage of WATSIM is that it is consistent with the CAPRI-model. A continuous data flow between these two models has been established, and model interactions have been explored in several policy-oriented applications. During the last months an explicit linkage between CAPRI-model and the WATSIM-model has been established.

5.3 Supplementary Tools without EU-wide coverage

5.3.1 Regionalised agricultural and environmental information system (RAUMIS)

References

GEIER, U., M. MEUDT, B. RUDLOFF, und G. URFEI, (1998) : Entwicklung von Parametern und Kriterien als Grundlage zur Bewertung ökologischer Leistungen und Lasten der Landwirtschaft – Indikatorensysteme -, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Forschungsbericht 108 01 139, Bonn.

[3] The IFPRI-model has been established by a research team of the International Food Policy Research Institute at Washington D.C. It is a partial equilibrium model for agricultural commodities, which is mainly used for long-term simulations of world market developments. See e.g. ROSEGRANT, M.W, AGCAOILI-SOMBILLA, M, PEREZ, N.D.:. (1995): Global Food Projections to 2020: Implications for Investment. Food, Agriculture, and the Environment Discussion Paper 5. Washington: International Food Policy Research Institute.

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MEUDT, M. and W. BRITZ (1997): The CAPRI Nitrogen Balance, CAPRI Working Paper 97-04, University of Bonn.

WEINGARTEN, P. (1995): Grundwasserschutz und Landwirtschaft, Eine quantitative Analyse von Vorsorgestrategien zum Schutz des Grundwassers vor Nitrateinträgen, Dissertation, Bonn.

Since 1993 the modelling system RAUMIS is implemented at the German Federal Ministry of Agriculture (BMVEL), Bonn and the Federal Agricultural Research Centre (FAL), Braunschweig. Since 1997 RAUMIS is also applied by a newly established group at the Research Association for Agricultural Policy and Agricultural Sociology (FAA), Bonn.

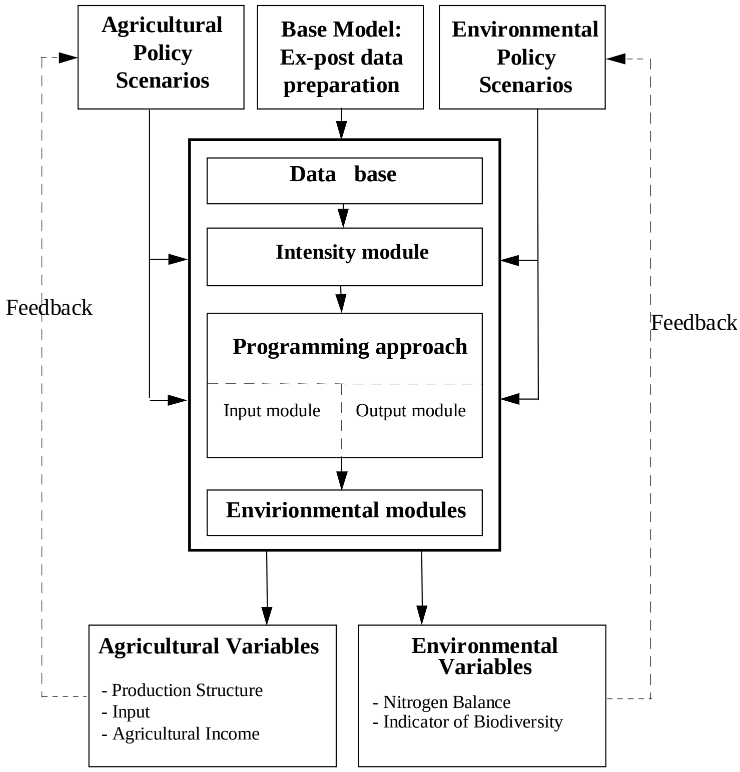
RAUMIS was designed as a national policy advice tool to support policy-makers in the agriculture reform process. The system illustrates impacts of alternative agricultural policies on agricultural production in Germany on a regional scale and offers the possibility to analyse both the economic impacts on agricultural income, production quantities and factor stocks as well as environmental impacts of agricultural production by a comprehensive set of environmental indicators.

Methodological approach

The methodological concept of the modelling system RAUMIS is an activity based non-linear programming approach, which is medium term oriented in forecasting. The model is able to cover the entire agricultural sector according to the definition of the Economic Accounts of Agriculture and consequently consistent to the agricultural sector. The activities are differentiated into 77 crop activities (including set-aside programmes and less intensive production systems) and 16 activities for animal production. The model comprises more than 50 agricultural products, used inputs, and therefore pictures completely the German agricultural production with its intra-sectoral linkages.

In the figure the construction of RAUMIS is shown in the case of the definition of less intensive production activities as an example. Different information sources of the overall database are combined to a consistent frame. Apart from the calculation method based on regional data units the highly disaggregated mapping of results and the close combination of the environmental and economic coherences are the strengths of RAUMIS.

General construction by assembling different section modules



Source: RAUMIS (1995), Institute of Agricultural Policy, Bonn.

The mathematical programming model consolidates various data sources by joining a bundle of official agricultural statistics and needed calculation data. The whole database of RAUMIS is consistent with the agricultural sector economic accounts.

The model results are mapped up to more than 340 regional units based on the German regional administrative level (as German 'Landkreise') NUTS III. A further improved consideration of natural locations i.e. on the lower municipality level is possible, depending on the availability of adequate data.

Environmental indicators

With respect to the emission and absorption of greenhouse gases the following environmental parameters integrated into RAUMIS are relevant:

1. nutrient input use and nutrient balances
2. extensifation potentials by less intensive production alternatives
3. single greenhouse gas emissions and global warming potential

Nutrient balances

The calculation of different positions in the RAUMIS nitrogen balance is based on an activity-based framework. In order to obtain regional input and output positions, activity-specific coefficients are multiplied with the level of each activity (harvested ha resp.. herd size) and afterwards aggregated over the activities.

Elements of the RAUMIS nitrogen balance

Nitrogen Output or 'losses'	**Nitrogen Input**
Nitrogen uptake by plants Ammonia 'losses' during storage *Balance:* denitrification potential, leach out potential	Fertiliser Manure Symbiotic fixation Asymbiotic fixation Asymbiotic fixation atmospheric input Atmospheric input

Less intensive production alternatives

The explorative tool has been developed in order to depict less intensive production alternatives, which are of major importance for the region under study. The RAUMIS-*NRW* is used to analyse future potentials for extensification and impacts of policy measures at German Land level. The modelling system is an activity-based approach, which represents the agricultural sector of North Rhine-Westphalia according to the Economic Account for Agriculture (EAA) by 31 regional models, representing the interdependencies between agricultural production and the environment by environmental indicators.

Based on the concept of neo-classical yield functions, the optimal special intensity for yield-enhancing inputs is determined on the basis of the relative product/input price ratios. This concept results into the ‘intensity module’. A set of alternative mechanical/technical processes is defined for plant production (traditional tillage by plough, reduced tillage (cultivator), no-tillage and extensive grassland production) that differ according to the use of machinery and thus decision-related depreciation costs, labour requirement, yield, yield-enhancing inputs and other variable costs. That implies the module for less intensive production alternatives.

Greenhouse gas emissions

With respect to the activity-based account approach of RAUMIS the estimating of single gas emissions from direct and indirect sources was implemented using a set of standardised validated coefficients from the literature. While indirect emissions stem from input production (e.g. fertiliser, pesticides) the direct ones accrue directly from agricultural production. The most significant direct emissions of agricultural production are CH_4, N_2O and CO_2, whereas N_2O can largely be attributed to crop production and CH_4 to animal production in particular ruminants.

Based on these specifications RAUMIS can calculate global warming potentials depending on the retention time of the relevant gases in the atmosphere. Converting the gases into carbon dioxide equivalents provides a different risk-potential of each greenhouse gas for the greenhouse effect with respect to the political settings of climate reduction objectives.

Especially the including of the over all CO_2 balance positions for a more comprehensive calculation of the potential agricultural contribution, important additional carbon-sinks are forests (CO_2) in a long term perspective. The second possible amplification is a differentiation by defining alternative production alternatives e.g. traditional tillage by plough, reduced tillage (cultivator), no-tillage and extensive grassland production (CO_2, N_2O). So far these sinks (or emission sources) depending from different cultivation practices (e.g. use of plough) are important in a short or medium term perspective.

Evaluation

With respect to the explorative approach to specify the model in balancing the over all range of carbon dioxide sources and sinks the summarising characteristics and challenges of RAUMIS are:

- The general activity based account approach of RAUMIS is advantageous with respect to balancing the differentiated emission sinks and sources. Particularly the 'bottom up principle' allows a highly detailed specification of both the direct and the indirect emission factors concerning each production unit as one average emission value.
- So far the RAUMIS approach to assess green house gas emissions is straightforward, particularly for CO_2 emissions. The proposed model extension is feasible because of its general construction. The model is able to fulfil the requests of the actual required detailed calculations of the carbon-sinks.

With respect to the defined evaluation criteria, RAUMIS as a model for the German agricultural sector can certainly not meet the criterion for a whole coverage of the EU. And it would be time and labour consuming to transfer RAUMIS to all EU-Member States. However, the parts of the RAUMIS database which concern carbon sequestration and greenhouse gas abatement strategies, should (in as far as it is feasible) be incorporated into the model for the whole EU which is to be developed. The same applies to output variables from RAUMIS, which are applicable to both Germany and other EU-Member States. Finally, RAUMIS could be used as a reference solution in order to test the quality of the more aggregated EU models, which are to be developed.

5.3.2 Process-based Economic Farm Models

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CARA DE, S. and JAYET, P. A. (2000): Emissions of Greenhouse Gases from Agriculture: The Heterogeneity of Abatement cost in France.

Planification of production and investment has a long tradition on farm level. The majority of economic farm models is based on the Linear Programming Method. This is composed of a series of equations which, for a given amount of production factors and rights, enables the user to simultaneously optimise production on farm level under economic and ecological objectives. Most recently, environmental aspects and objectives have been established such as the impact of agriculture on the emission of greenhouse gases and respective abatement strategies for various farming systems. These models can lead to concurrent solutions for multi-dimensional problems. They consist of different modules which are able to represent all relevant production systems in arable and grassland farming including the necessary mechanisation, as well as animal husbandry with a highly disaggregated feeding modul, use of liquid manure and nitrogen balance of the farm. Within these models, all energy, emission and flux parameters are integrated, which are relevant for the quantification of farm-level greenhouse gas and ammonia emissions. With the help of such complex economic-ecological farm 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. The projection of such simulation results for farming systems, with relevant multipliers, to agricultural areas or regions, allows for a quantification of mitigation potentials and abatement costs on farm and regional scale. Results represent greenhouse gas emissions for CO_2-equivalents and individual gases referring to farming systems, surface units (e.g., hectare), production units (e.g., grain units), animals (e.g., dairy cow) or livestock units.

On the farming system level exist surprisingly few highly disaggregated models which are suitable for modelling abatement strategies for greenhouse gas emissions and in particular policy options for carbon sinks. A literature review has so far identified only two groups with relevant work in this field:

- Universität Hohenheim, Department of Farm Management
- INRA (Institut nationale de la recherche agronomique), University of Paris

The models in both working groups are based on linear programming. The models were applied to representative farms in Southwest Germany and a representative selection of farms in France.

The models include emission factors and regression equations to reflect greenhouse gas emissions from agriculture. The following emission sources and sinks are distinguished:

1. ruminant methane emissions depending on feeding
2. nitrous oxide emissions depending on nitrogen application
3. carbon enrichment in soils through afforestation

It was the aim of the French models to derive shadow prices caused by emission reductions for different farm types in France.

The farming system models of the Hohenheim group where developed in an interdisciplinary collaboration within the Graduate College 'Mitigation Strategies for the Emission of Greenhouse Gases and Environmentally Toxic Agents from Agriculture and Land Use" and the Research Group 'Measurement, modelling, and mitigation of greenhouse gas emissions from farming systems", both funded by the German Research Foundation (DFG). The models consist of different sub-models: a module reflecting all relevant plant and grassland production activities and the respective mechanisation, an animal nutrition module, a manure management module, and a nitrogen cycle module. All relevant parameters on energy, emission, and substance flux, which are needed to quantify greenhouse gas and ammonia emissions from agricultural systems, are integrated into these sub-models. On the basis of these models, emissions from agricultural systems as well as ecological and economic effects of abatement strategies could be determined taking a large number of influencing parameters into account.

In the medium run the working group from Hohenheim is planning to apply the linear programming model to representative farms from the Farm Accountancy Data Network (FADN) of the EU. Using the FADN aggregation factors the individual farms can be aggregated to the regional level. This procedure however is problematic because of the lacking interdependence of farm models. An agent-based approach could offer a solution to this problem even though there still exist size, time and mainly computability restrictions which make it difficult to develop regional or sector models on the basis of highly disaggregated farm models.

Evaluation

At present neither the French nor the German approaches are developed to a stage which allows for the representation of a very large number of different representative farming systems, nor can single models be used as an instrument for policy advice of decision makers on the EU level. Similar to the RAUMIS model, farming system models represent valuable data sources for more aggregated modelling approaches.

Farming system models on the basis of linear or quadratic programming are particularly suitable for modelling and optimising the various interdependencies between different farming practices and abatement strategies. They are particularly suitable for a representation of substitution processes induced by policy measures, which are also subject to the underlying normative behavioural assumptions (it is known that these often do not correspond with reality). Farming models can be coupled quite easily with different location factors to incorporate soils, weather conditions etc. Conventionally they can also be linked to site-specific simulation models like DNDC, EPIC, GLEAMS etc. Interdependencies between management practices, greenhouse gas emissions, and other environmental impacts such as nitrate leaching, ammonia losses, plant protection measures are considered implicitly and can be quantified. Soil erosion through wind and water can only be simulated if local soil and climate conditions are very strictly defined.

Farming system models are a valuable supplementary data source for models at a higher level of aggregation. It is both the initial data input into farming system models and the model results which can be used with more aggregated models.

The working groups at INRA/University of Paris and Hohenheim have published emission parameters and their impact on greenhouse gases and other environmental impacts (except soil erosion) for almost the complete range of technical measures in the fields of fertilisation, feeding, animal production, manure management, biogas plants, biomass production, and others. Results were published on the effects of policy measures such as a CO_2-tax, a nitrogen tax, emission equivalents taxes, emission quotas, emission trade, increased energy prices, etc. Generally it can be said that the more farming system models exist, the better is the data base for policy oriented modelling systems on higher levels of aggregation. Therefore, it is highly desirable to model farming systems not modelled so far and to further develop existing farm based approaches.

5.3.3 Site-specific models

The role of soils as an emission source or sink of greenhouse gases not only depends on soil management practices but to a large extent also on the site-specific characteristics. Including all of these factors into agricultural or forestry models would be very laborious and it would increase the models' complexity significantly. However, it should be tested whether existing economic models could be augmented by some site-specific modules. Two approaches appear to be particularly promising. One is the application of simple regression models within a GIS framework. The other approach is the use of process-based ecosystem models.

Examples for regression models

This method has recently been used to obtain a more spatially differentiated inventory of greenhouse gases as compared to the IPCC method. With respect to N_2O emissions from soil regression models have been sufficiently tested, and it has to be seen whether a similar approach would be adequate for carbon sinks.

References

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As part of the EU concerted action FAIR3-CT96-1877, a method for the determination of greenhouse gases from agriculture was developed for the agriculture of the EU. Emissions were quantified on the basis of emission factors and regression equations, which were multiplied by indicators which can be derived from census data or digital soil maps. Regression models were mainly used for N_2O emissions from soils. On the basis of a larger number of emission measurements across the EU, regression models were built for agricultural soils in different European climate regions. During the development great emphasis was put on an easy application of this method to all EU-Member States and the inclusion of specific regional conditions at the same time. This regionalised inventory of biogenic greenhouse gas emissions is continued after the completion of the concerted action, and it is continuously updated with new emission measurements.

A multiple regression model was also developed for the UK from which a spatial inventory of N_2O emissions from agriculture and non-agricultural soils was derived to describe soil N_2O emissions from published field measurements in temperate climates. The regression model was then coupled with a GIS framework to estimate spatial distribution of N_2O emissions from soil.

<u>Evaluation</u>

Taking account of important soil characteristics is the particular strength of the regression approaches. The models were developed using all relevant investigations of soil emissions and other agricultural sources. Currently, the regression approach appears to be used exclusively for soil N_2O emissions. Whether a similar approach can be applied to carbon emissions and sinks has to be tested. The mentioned regression models have no economic basis. Therefore, they cannot be used for the derivation of marginal abatement cost curves. However, it has to be determined whether they can be integrated into economic models.

Process-based ecosystem models

Regional analysis of soil C requires the integration of dynamic simulation models, which represent the feedbacks and interactions between soil processes, with information about the biotic and abiotic variables which drive these soil processes. These models embody our best understanding of soil C dynamics and may be used to predict how global environmental change and agricultural management practices will influence soil C stocks, and to evaluate the likely effectiveness of different mitigation options. However, most models were originally developed to investigate questions of ecosystem behaviour at the site or patch level (e.g., a maize field, a pasture). Implicit in their formulation is the assumption that driving variables such as climate soil properties are homogeneous across the land area of the patch. Hence upscaling to the regional level may impose a major source of error in estimating the dynamics of soil C stocks, neglecting the inherent variation of most of the driving variables.

The simulation models presented here assume that soil organic matter (SOM) decomposition follows first-order kinetics, i.e., a constant fractional loss per unit time, of different organic matter fractions, with the potential rate being modified by a variety of soil environmental conditions. Consecutively three well-known ecosystem-models are described focusing on their usefulness in soil C modelling.

CENTURY

<u>References</u>

Model Homepage: http://www.nrel.colostate.edu/projects/century5/

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Model Development

The CENTURY model was developed to simulate long-term effects on soil and carbon dynamics, with a monthly simulation time step. The model was developed by the Natural Resource Ecology Laboratory at Colorado State University in Fort Collins, Colorado, in the late 80s. Since then a few modifications have been made and it is now available in version 5 from Colorado State University at the model homepage. The current version is actively maintained and very well documented. Additionally, its structure allows an extension of functionality since the source code is freely available and the software architecture follows a clear object-oriented design. It has been used to simulate carbon and nutrient dynamics for different types of ecosystems, including grasslands, agricultural lands, forests, and savannas. The model has the capability of simulating several nutrients (C, N, P). Due to the fact that the model uses a monthly time step and is designed for long-term carbon-sequestration, the nitrogen sub-model is represented very simply.

Model Structure

The CENTURY SOM sub-model has a multiple pool structure. The pool divisions are based on SOM decomposition characteristics, or turnover rates. It includes two litter fractions (metabolic and structural) and three organic matter fractions (active, slow, passive) differing in inherent decomposability and in the degree to which soil texture effects turnover rates. The principle driving variables are monthly minimum and maximum temperature and monthly precipitation. Other important soil process rate controls are soil texture, litter lignin and N content, and tillage disturbance.

Model Applications Related to Soil C

Among many simulation studies, the CENTURY model version 4 was tested against seven long-term data sets at field-scale from Europe and Australia. The model is capable of simulating trends of soil C over time across a variety of cropping systems but has limitations in forest stands. However, CENTURY had limited success predicting inter-annual variability in yield and N uptake, probably due to its constraints in the N sub-model. In the current version 5 the N sub-model is extended. Alvarez (2001), using the CENTURY model, estimated soil C loss by cultivation at regional scale for the Argentine Pampas for the last 400 years. This study used aggregated soil and climate data and was able to predict soil C content under pasture management.

Denitrification and Decomposition Model (DNDC)

References

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Model Development

The Denitrification and Decomposition Model (DNDC) was developed at the University of New Hampshire in the early 90s. Its original purpose was the simulation of N_2O and NO gas fluxes from agricultural fields on a daily basis but it also has a very detailed soil C sub-model. It is currently the most widely used simulation tool for N related gas fluxes and has been used for county based national inventories of N_2O for China, the USA and the UK.

Model Structure

The Soil Organic Matter (SOM) sub-model is made up of three different soil C pools with each being divided into a labile and resistant fraction. As in the CENTURY model these pools differ in decomposability and turn-over rate. The plant growth sub-model is rather simple modelling biomass at a potential growth rate which is modified by environmental factors. The driving key variables are climate, soil properties, and agricultural management.

Model Applications Related to Soil C

DNDC was run against the same long-term data sets as the CENTURY model mentioned above. Even though it has a very simple plant growth sub-model it was capable of simulating trends in soil C quite accurately. In another simulation study of an arid farmland ecosystem in China DNDC was also able to model the influence of different management practices on soil C content.

Erosion Productivity Impact Calculator (EPIC)

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Model Homepage: http://www.brc.tamus.edu/epic/

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Model Development

The EPIC model is one of the earliest agricultural simulation tools, and it was originally developed to assess the effect of soil erosion on productivity. It is maintained by Texas A & M University and available at the model homepage. In contrast to the two models mentioned above, EPIC also includes an economic sub-model.

Model Structure

EPIC has the simplest SOM model of the presented simulation models. It divides SOM into three different pools: the fresh organic pool of crop residue and microbial biomass, an active humus pool, and a stable soil organic humus pool. Only the fresh residue and the active humus pool are subject to mineralization. The model operates on a daily time step requiring about the same input data as CENTURY and DNDC.

Model Applications Related to Soil C

Since EPIC was not especially developed for simulation of soil C there is no literature available dealing with SOM solely. However, Bernados et al. (2001) studied the changes in agro-ecological functions during a 93-year farming period in the Argentine Pampas. EPIC estimated the analysed processes (e.g. crop yield, N turn-over, hydrology) within in the ranges of results of field measurements and experimental results.

Evaluation

The integration of suitable process-based ecosystem models into economic models of agriculture and forestry is an important step towards a spatially differentiated analysis of carbon sinks. Generally, process-based models require large data quantities of input data on soils, weather, plants, livestock, land use, and management practices. In addition to the data requirements, the necessary spatial and temporal differentiation of input data may be problematic as well. Since process-based models are usually located at a lower scale level than economic models it has to be investigated whether an integration of these models is reasonable and feasible. The aggregation of data may lead to error prone simulation results due to faulty input data. Recently, scientists have started trying to overcome these limitations by using stochastic simulation models to understand error propagation in their models. With respect to this there is a need for discussion and closer co-operation between the agricultural and forestry modelling community on the one hand and process-based modellers on the other hand. Possibilities for this will be explored during the next project phase and it will be further investigated whether any process-based models at higher levels of scale already exist, which were specifically designed for this.

5.4 Comparative assessment and ranking of the selected models

The comparative assessment and ranking of models in agriculture (and forestry) is based on the evaluation criteria discussed in chapter 4. For the European Commission, the analysis of marginal abatement costs for CO_2 emissions and the increase in CO_2 sinks, respectively, stand to the fore. At least in where agricultural sources are concerned, greenhouse gas emissions which do not consist of CO_2 are relevant enough to be used as evaluation criteria, too. Furthermore, chapter 5 mentions some more essential criteria which, above all, comprise the dominance of production systems to be differentiated, the spatial resolution of models on an EU-wide scale, the economic optimisation mechanism, trade-offs with other environmental objectives, welfare effects, further implications for the environment and the costs as well as time exposure of analysis and simulation models.

Criteria like employed software and model solver algorithms, which are useful to assess the procedure to establish links between models, cannot be taken into account yet, since they are not sufficiently described in available publications. Some considerations on this issue will be provided in chapter 8.

Another important rating criterion is the proper representation of competitive and substitutional relationships between agriculture and forestry, especially with regard to land resources. Although a simultaneous agri - silvicultural model would be desirable and, in the long term, seems to be feasible, comparison and ranking of models for the time being has to be carried out separately for the two modelling ranges. This especially holds true in view of the fact that, currently, such simultaneous models are unavailable.

The synopsis which is presented in Table 1 lists the existing models which are of importance for the objectives of the European Commission, and which have been discussed in chapter 6. The ASMGHG, developed at Texas A & M University, is based on data from agricultural statistics from the USDA, and focuses on greenhouse gases, mitigation strategies and marginal costs of policy options in US agriculture. The model represents 63 regions throughout the USA. The strengths of the model are its sufficient covering of the production diversity, a disaggregation which obviously seems to be appropriate for the USA, considering, as an EPIC-based integrated model, site-specific differences, too. Another strong feature is the economic steering mechanism. The weaknesses, however, lie in the fact that non-CO_2 gases are not adequately taken into account. Especially N_2O emissions can only be considered very roughly with EPIC. Furthermore, welfare and distributive effects are analysed in a fragmentary manner. In case this model structure were to be made the basis for the whole EU, the complete EUROSTAT database would have to be re-compiled and calibrated once more, and the model design would have to be adjusted to the conditions of the EU and the CAP. Some considerations on this issue will be taken up in chapter 8.

Within the GECS project which brings together highly competent research centres to work interdisciplinarily on simulation as well as economic, energy and ecological impact analysis level which is focussed upon changes with the type of integrated model. While, for the macro-economic GEM-E3 model, the 15 member countries of the EU are in the forefront, world agriculture is just divided into further 13 regions in the agricultural sector model (AEM) of the IMAGE compound model. Generally speaking, IMAGE 2.2 differentiates 19 regions worldwide. Spatial resolution of the natural science oriented models is 0.5 km x 0.5 km. A strong point is the merger of models developed by all concerned scientific disciplines. Similarly, ASMGHG for the USA, this is a compound model integrating some economic steering mechanisms. The weakness of the compound approach is the unsuitable disaggregation of agricultural production processes and management options, as well as of site-specific non-CO_2 emissions from agriculture. Modelling of economic interactions within the agricultural sector is intended, yet implemented only superficially. Currently it can not be concluded, how the representation of the agricultural sector in the EU would be improved by Agri-Pol.

CAPRI and WATSIM were developed by a network of European Research Institutes. CAPRI has incorporated a high degree of regional and product specific disaggregation in EU-Member States on the NUTS II level. Both models are consistent, with the latter one considering agricultural trade effects worldwide, presenting allocation and distribution effects for political analysis especially well. The strengths of the harmonised models can be seen in the high level of acceptance with political decision makers, due to long lasting experiences in political analysis in the EU (CAP-reform, AGENDA 2000, etc.). Weak points within the current versions of both models consist of a lack of carbon sinks coverage and an insufficient consideration of non-CO_2 gas emissions and a lack of interaction of site in the area of specific emission effects. From another point of view, however, the costs and time requirement for the adoption of these models, when compared with the aforementioned ones, would be relatively low.

Process-based economic farm models have been specified only for some farming systems so far. They are indispensable for quantifying differentiated impacts of technical mitigation strategies and political instruments with regard to potential CO_2 sinks in agriculture. They form the data and evaluation basis for the analysis of the impacts of recent and current research results and their implementation in extension and policies. These models have their strength in representing trade-offs between CO_2 abatement and respective costs, as well as other environmentally important criteria such as erosion, nitrate leaching, ammonia emissions, etc. They have comparatively low financial and time requirements for development and simulation, but they are not representative. Therefore their results have to be integrated into regionalised agricultural sector models.

The **site-specific models** which were examined for the purpose of this study vary with regard to their complexity, spatial resolution and data input requirements. Regression models for the EU and the UK were developed for regional focussing purposes, they show a simple mathematical structure and require comparably few input data. Their strength lies in their relatively exact representation of climate relevant N_2O emissions from agricultural soils, which are based on soil maps. Currently, such regression models do not exist for CO_2 sources and sinks in soils. In comparison, CENTURY, DNDC and EPIC have to be seen as highly complex simulation models for modelling nitrogen and carbon dynamics of soils. Here, source and sink functions of examined soils for N and C can be assessed. Originally, these models were developed for simulations on field scale. The quality of simulation results is highly dependent on the quality of input data. When using these models on regional and country levels, respectively, errors in aggregation have to be assumed. These models can contribute largely to carbon sink analyses, yet they cannot be simultaneously integrated into statistically based, economically oriented regional models. Due to the fact that no site specific model contains economic key figures and mechanism, they are not suitable as stand-alone solutions for the representation of CO_2 abatement costs and marginal cost curves, respectively.

Altogether, the comparative analysis shows that the ASMGHG model, which is used in the USA for policy analysis and consultancy, is not useful for the EU for reasons of cost and time intensiveness. The agriculture model which actually is available within the framework of the GECS project is to be overhauled and the concept remains to be refreshed before a further evaluation following the afore mentioned criteria can take place. It has so far not been used for impact analysis of agricultural policies and is not calibrated to the EUROSTAT data base. Therefore, the GECS-Model can not be recommended as a tool for carbon sinks and abatement strategies on its own, and also not as a starting point for further model development.

It is now very clear that, for the analysis and simulation of CO_2 abatement and carbon sinks strategies, a compound model comprising site specific models, process-based economic farm models, regional models and also world models have to be developed. At first, they should represent a baseline scenario for the agricultural sector as well as the presumable policy options. The models have to adequately communicate with each other, they also must, in an iterative link-up with forestry models, image the competitive and substitution processes concerning land use for production of food and biomass. At the moment, it might to be the silver bullet to link this model compound (WATSIM, CAPRI, farm and site specific models) with the GECS project whereby especially the interactions regarding energy and environmental policies, taken from GECS simulations, could figure as exogenous variables in carbon sink models. But the first best solution seems to be to integrate some elements of GECS into a new designed modelling concept for the analysis of carbon sink and abatement strategies for agriculture and forestry (see section 8).

Table 1: Synopsis of Relevant Models Incorporating GHGE Mitigation Options and Agricultural Carbon Sinks

Name of model or model framework	Developing Institution	Economic sub-model and/or data base	Focus of model	model scale	strengths	weaknesses	Consideration of GHG: carbon sinks	Consideration of GHG: other GHG
ASMGHG, EPIC, FASOM	Texas A&M University	Agricultural census data USDA	GHGE and mitigation options from US agriculture	USA **Partition:** 63 Regions	**(1), (3), (5), (6), (7), (4)**	**(2)**	**(+)**	**(+)**
GECS and IMAGE	JRC-IPTS Seville, Federal Planning Bureau Brussels, CIRAD-ECOPOOL Paris, ICCS-NTUE Athens, ZEW Mannheim, CES-KUL Leuven,RIVM Bilthoven	GEM-E3	Interaction between economy and environment and energy system	EU **Partition:** 15 Member States	**(2), (3), (6), (7)**	**(1), (4), (5)**	**(+ [a])**	**(+ [a])**
		AEM	Demand of food, feed and wood products	World **Partition:** 13 Regions	**(1)**	**(2), (3), (4), (5), (6), (7)**	**(+[a])**	**(+ [a])**
		Agri-Pol	Estimate Marginal Abatement Cost curves for carbon for agriculture and forestry	Partition: 40 regions, European countries are specified one by one	**(2), ?[b]**	**(7), ? [b]**	**(+ [a])**	**(+ [a])**
CAPRI	Network of European Research Institutes	Sectoral Accounting Data Agricultural census data EUROSTAT	Policy analysis of agricultural markets	EU **Partition:** 200 Regions (NUTS II)	**(1), (2), (3), (6), (7)**	**(4), (5)**	**(-)**	**(+)**
WATSIM	University of Bonn	Agricultural census data EUROSTAT	Policy analysis of agricultural markets	World **Partition:** 15 Regions	**(1), (2), (3), (6), (7)**	**(4), (5)**	**(-)**	**(-)**
RAUMIS	University of Bonn	Agricultural census data	Policy analysis of agricultural markets	Germany **Partition: 340 Regions**	**(1), (3), (4), (6), (7)**	**(2), (5)**	**(-)**	**(+)**

[a] The GHG do not necessarily have to be included explicitly in the model but they are being accounted by the linkage with the IMAGE model

[b] Currently, a final assessment of Agri-Pol is not possible due to a lack of scientific publications

(1) Production coverage **(2)** Regional coverage **(3)** Economic steering mechanism **(4)** Trade offs with environmental quality
(5) Site specific effects **(6)** Allocation and distribution effects **(7)** Reputation and status of application of the model
(+) covered by the model **(-)** not covered by the model

Table 1: continued

Name of model or model framework	Developing Institution	Economic sub-model and/or data base	Focus of model	model scale	strengths	weaknesses	Consideration of GHG	
							carbon sinks	**other GHG**
Process-based economic farm model	INRA/University of Paris	Agricultural census data	Impacts of afforestation on set-aside land, abatement cost	Farm, Sector (France)	**(1), (3), (5),**	**(2), (4), (6)**	**(+)**	**(+)**
Process-based economic farm model	University of Hohenheim	Empirical Data farm accounts	Evaluation of abatement strategies and related costs	Farm (Germany)	**(1), (3), (4), (5),**	**(2), (6)**	**(-)**	**(+)**
Regression model	Universität Stuttgart (FAIR3-CT96-1877)	Agricultural census data soil maps	Inventory of biogenic agricultural greenhouse gases	EU **Partition:** 15 Member States (NUTS 1 and 2 level)	**(2), (5)**	**(1), (3), (4), (6)**	**(-)**	**(+)**
Regression model	CEH Edinburgh, University of Edinburgh	Agricultural census data	Inventory of soil N_2O	UK **Partition:** 5 km^2	**(5)**	**(1), (2), (3), (4), (6)**	**(-)**	**(+ c])**
CENTURY	Colorado State University	Soil and meteorological date, agricultural census data	N and C dynamics in soil	Original field scale, meanwhile also regional scale	**(4), (5)**	**(1), (2), (3), (6)**	**(+ c])**	**(+ c])**
DNDC	University of New Hampshire	Soil and meteorological data, agricultural census data	N and C dynamics in soil	Original field scale, meanwhile also country level (e.q. USA, China, UK)	**(4), (5), (7)**	**(1), (2), (3), (6)**	**(+ c])**	**(+ c])**
EPIC	Texas A&M University	Soil and meteorological date, agricultural census data	N and C dynamics in soil	Original field scale, meanwhile also country level (e.q. USA)	**(4), (5)**	**(1), (2), (3), (6)**	**(+ c])**	**(+ c])**

c] Only the soil related GHG caused by agriculture

(1) Production coverage **(2)** Regional coverage **(3)** Economic steering mechanism **(4)** Trade offs with environmental quality
(5) Site specific effects **(6)** Allocation and distribution effects **(7)** Reputation and status of application of the model
(+) covered by the model **(-)** not covered by the model

6 Overview of existing forestry and forest sector models

The following gives an overview of existing models regarding analyses of forestry and carbon sequestration. On this topic exist fewer models in the forest sector than in agriculture which are relevant for economic analyses, as most of the models related to forestry have no economic aspects included (cf. Nabuurs and Paivinen 1996). The report concentrates on describing models which are manageable and relevant in a European context and which today incorporate (or can incorporate) the rather heterogenic structures of the European forests and forest industries.

The following models are considered: EFI-GTM, EFISCEN, GAYA-JLP, and CO2FIX. Of these, only EFI-GTM and GAYA-JLP can be classified as economic models, but the other models are included because they are potentially important as sub-models for input into the economic models.

6.1 World models

6.1.1 EFI- GTM

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EFI-GTM is a forest sector model. By forest sector models we mean models which include both forestry (as a supplier of roundwood and forest fibre) and the forest industries (as demander of the roundwood and chips). Several forest sector global trade models exist, but the EFI-GTM model is the one with the highest relevance for carbon sequestration and forest sector analysis in the EU context as it treats each country in Europe as one region. At the same time it includes all other regions in the world, but on a higher aggregated level than countries. A vital element of the model is that transport costs are included between each of the regions and for all products.

EFI-GTM is a regional and multi-periodic partial equilibrium model of the global forest sector and is now up-dated and operated by the European Forest Institute in Joensuu, Finland (Moiseyev and Solberg 2001). The model originates from the global trade model (GTM) of the forest sector products developed and described by Kallio, Dykstra and Binkley (1987). The model is intertemporal but static in the meaning that it seeks an equilibrium solution for one period at time, and then updates the input data for the subsequent period (Salo and Kallio 1987). One important factor which links the periods are the new investments implemented if prices and costs give high enough profitability. Another dynamic factor is the forest growth, which depends upon growing stock and harvest volumes.

The regions in the model are assumed to trade commodities whenever the trade increases economic welfare in the regions. It is assumed that consumers maximize their utility and that producers maximize their profits (Samuelson 1954). For each region supply functions for production factors are defined, as well as a set of fixed-input technologies with specific capacities for producing intermediate and final products. All the agents in the model are assumed to behave competitively and the equilibrium solutions in the model simulates competitive behaviour.

Each country in Europe is one region in the model. In addition 10 Asian, 5 North American, 3 Russian, 6 Latin American, 2 Oceanian, and 4 African regions are included making the system a global model linked through the transport costs between each region for all products. In the newest version of the model, data for the year 1999 is used. These include data for 61 world regions, 36 forest products (25 forest industry products, 5 types of roundwood plus chips and 5 types of waste paper) and for each European country 3 types of technologies – corresponding to low, high and average production costs ("technology" means here a specification - for each product - of the production input required of labour, energy, timber (or pulp), chemicals and "other" components per ton product produced).

Non-linear optimization solver MINOS is used in combination with the optimization software GAMS.

The base year demand for the final products (sawnwood, panels, paper and paperboard) is calculated from production, import and export FAO data. The demand for final products in the following years is computed using equations which describe quantity demanded as a function of prices and GDP. Price and GDP elasticities for the final product demand equations are from FAO (1997). Demand for intermediate products (sawlogs, pulplogs, chemical and mechanical pulp) derives from the demand for the final products through input-output coefficients for each technology activity in each region. Each technology activity (process) is described in the model by material input coefficients, production capacity and processing costs.

The regional wood supply is described by a supply equation, where supply is a function of price and growing stock. For each region there is a forestry submodel where the forest growth is decided by the biological growth and the annual harvest. If the annual harvest in a region is less than the net annual forest growth, the growing stock increases thus increasing the biological growing stock volume as well as the carbon sink. In addition, the model includes another dynamic factor as increased growing stock increases roundwood supply according to the elasticities specified. As such the growing stock is a so called 'shifter" of the supply curve.

The carbon sink and GHG aspects can easily be integrated in this model in several ways. First, the changes in forest growing stock give directly the corresponding changes in carbon sink in the forests for each country/region. Secondly, the model solutions give endogenously the end usages (to bioenergy, sawnwood, fibreboards, paper etc) of the harvested roundwood, and thus the carbon sequestration in those products. Third, the above mentioned technology-activities makes it possible to illustrate the carbon sink impacts of potential changes in energy prices (for example a carbon tax is likely to change the energy prices, which again in the model will change the productin costs, which then will change the demand and supply etc.). Finally, because the model includes transport/trade, the leakage problems related to carbon sequestration in forests can be analysed better than in other types of existing models.

The present version of the model does not include carbon sequestration aspects directly, but can easily be modified to do so.

Evaluation

The strong points of the EFI-GTM model are:

- based on economic theory,
- the regional coverage makes the model well suited for meaningful EU analysis,

- international trade aspects and end-use of forest products are well covered, and thus the greenhouse gas impacts of changes in industry and trade structure as a function of for example changes in CAP,
- in operation today (except that bioenergy and the carbon sink aspects have to be specifically included – which is easily done)
- can be further divided into sub-regions of a country if data allow.

The weak points of the model in relation to carbon sink issues are that the forestry sub-model is rather rough, and that environmental aspects related to forestry other than GHG effects have to be incorporated exogenously. However, these weak points can be met by combining exogenously the forestry sub-model in EFI-GTM with the more detailed forestry model EFISCEN which is described in the next chapter.

6.2 EU – models

The EFI-GTM model is a global model with focus on Europe, but it can also be classified as an EU-model because, as mentioned, each country in EU is incorporated as one region in the model. In addition, another model – EFISCEN – which is a pure forestry model, exists operating at country level in Europe as described below.

6.2.1 EFISCEN

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The European Forest Information Scenario model (EFISCEN) is a forest resource assessment model, especially suitable for strategic, large scale (> 10,000 ha) and long-term (20 – 50 years) analysis. EFISCEN 2.0 is suitable for assessments of the future state of the forest under assumptions of future felling levels. The model simulates the state of forest under assump-tions of future felling levels and forest silviculture activities. The model has no economic variables and does not use any optimisation, but simulates the state of forest resources under management regimes defined by the user.

The main advantage of this model is that it is not very data intensive. It requires rather basic forest inventory data which most European countries have available. The basic output of the model consists of the state of the forest at five year intervals, e.g. growing stock, increment, felling and age class distribution.

The core of the growth simulator of the EFISCEN 2.0 model is based on a model developed for even-aged forests at the Swedish University of Agricultural Sciences (Sallnäs 1990). The original aim was to develop a forest growth model that could be incorporated in a forest sector model. Later in the early 1990's it was modified and used by IIASA (International Institute for Applied Systems Analysis) to study the effect of air pollution on European forests (Nilsson et al., 1992).

Nowadays EFISCEN is in use and under further development at the European Forest Institute (EFI) for new forest resource projections at the European level (Nabuurs et al., 1998; Päivinen and Nabuurs 1997) and in Russia (Päivinen et al., 1999; Lioubimow et al., 1998). At EFI it has been validated with historical data (Nabuurs et al., 2000).

In the EFISCEN 2.0 version the following adaptations were made to the model compared to earlier version:

- Thinnings were incorporated in a different way in the model, resulting in a more realistic increment after thinning.
- The increment rates at high growing stocks were modified.
- All calculations are now carried out for five years age classes.
- Transient increment rate changes due to e.g., environmental changes can now be incorporated.
- Full forest biomass balance can be calculated including soil carbon and carbon in roots, branches and stem biomass.

The EFISCEN model is under constant development and version 3.0 will incorporate natural mortality rates and a stochastic approach for natural disturbances (Schelhaas et al., in press). The EFISCEN version 4.0 will incorporate a multi-country module that links the countries through consumption rates and wood products trade flows (Nabuurs et al., in press).

Some countries in Europe report their forest inventory data by diameter classes, which create a need for a different modelling approach. This so called unevenaged approach is in use for parts of Belgium, France and Italy and the whole of Spain. The development of this element to EFISCEN is underway.

EFISCEN is a timber assessment model, which means that the user specifies a certain harvest level and the model checks if it is possible to harvest that amount and simulates the development of the forest under that harvest level. The forest area is first divided into forest types. For each country, different forest types can be distinguished by region, owner class, site class and tree species depending on the level of detail of the input data. For each forest type the following data should be available for each age class:

- area (ha)
- average standing volume under bark (m3 ha^{-1})
- net current annual increment over bark (m3 ha^{-1}).

Further, information is needed about the management regime, such as thinning regime, thinning intensity in the past, and final cutting ages. If the carbon budget of the forest area is to be calculated, then biomass distribution parameters, weather data and litter production data are needed as well.

The length of the simulation period can be altered by changing the number of five year time steps. However, the credibility of results decreases in long-term simulations and the results after about 50 years simulation should not be taken as realisation of real situation, while errors accumulate in the model.

The forest growth models used in EFISCEN can in principle easily incorporate increases in growth caused by for example carbon fertilization due to increased atmospheric concentration of CO2, assuming one has good empirical data on the growth increases caused by such fertilization.

Biomass and litter production

Based on the calculated standing (stem) volumes by EFISCEN, the model calculates the biomass of branches, coarse roots, fine roots and foliage. For this calculation the model requires biomass distribution tables by age classes. These tables are the result of more detailed models, e.g., process based models, or are based on values taken from the literature. The biomass distribution is defined by regions and tree species. It is also possible to change the biomass distributions over time, for example because of climate change.

Each year a proportion of the stems, branches, roots and leaves of the trees die, resulting in litter production. This litter production is calculated, and it is possible to change the proportions of litter production over time. For these calculations a proportion of annual litterfall of the standing biomass is needed. Also, when a thinning or final felling is carried out, all biomass of the other tree components is added to the litter production and this litter production depends on the harvest level in the region. There is also a possibility to simulate the efficiency of forest operations through defining a proportion of felled stem wood actually taken from the forest.

Soil

The EFISCEN model contains the YASSO dynamic soil carbon sub-module that calculates the amount of carbon in soil. YASSO, described by Liski & Palduo (2001), models the decomposition of organic matter in upland forest soils. It consists of 3 litter compartments describing physical fraction of litter and 5 compartments describing microbial decomposition in soil. Each of these compartments has its own fractionation or decomposition rate. These rates represent fractions that are removed from the contents of the compartments during each time step. The current version of the model operates on a yearly time step.

In the model, litter entering the soil is first divided into the litter compartments according to its origin, i.e., foliage, branches, stem, coarse roots or fine roots. The fractionation rates determine the proportions that leave each of these litter compartments annually. This leaving matter is then divided for the soluble, holocellulose and lignin compartments according to its chemical composition. Fractions of matter leaving the soluble, the cellulose, the lignin or the humus compartments are transferred to the subsequent compartments, while the rest leaves the system.

The decomposition rates of the soluble, the cellulose and the lignin compartments as well as the transfer fractions between these compartments have been determined using mass loss data from Sweden (Berg et al., 1991a, 1991b). These parameters have been set to depend on annual temperature and precipitation minus potential evapotranspiration between May and September according to an analysis of Berg et al. (1992) data and a validity test (Moore et al., 2000). The parameters related to the humus compartments have been determined using data on the accumulation of carbon along a soil chronosequence on the Finnish coast The decomposition rates of the humus compartments are set less sensitive to climate than those of the other compartments (Liski et al., 1999, Giardina & Ryan, 2000).

Evaluation

The strong points of this model are:

- includes all countries in EU and is in use today,
- can be used to analyse wood volume and carbon sink impacts of changed harvesting strategies and planting activities (for example impacts of planting more on marginal agricultural land),
- can be used exogenously as input to the EFI-GTM model,
- soil impacts included,
- can be further divided in sub-regions of a country if data allow.

This model has as main weak point that no economic aspects are included. The forest growth functions are also in this model rather rough, but this weak point can be met by supplementing with information from using the CO2FIX model for certain "difficult" types of forest stands

6.3 Country level

Both EFI-GTM and EFISCEN can be used at the country level. In addition, a rather advanced forest management model, GAY-JLP, is of considerable interest not least because it is the only forest management model untill now which has been used for economic optimimization analyses taking explicit consideration to carbon sequestration in forest management in a European country (Norway).

6.3.1 GAYA-JLP

References

HOEN, H.F. 1990. Theoretical and empirical studies of long range forest management planning. Agric. Univ. of Norway, Dep. of For., Doctor Scientiarum Thesis 1990:23. Ås-NLH. 144 p.

HOEN, H.F. and EID, T. 1990. A model for analysis of treatment strategies for a forest applying stand simulations and linear programming. Res. Pap. 9/90 from the Norwegian For. Res. Inst. 24 p. + appendixes. (In Norwegian with English abstract).

HOEN, H.F. & SOLBERG, B. 1994. Potential and economic efficiency of carbon sequestration in forest biomass through silviculture management. Forest Science (40).3:429-451.

MARKLUND, L.G. 1988.Biomass functions for pine, spruce, and birch in Sweden. SLU report Department of Forest Survey.No. 45. Umeå.. Sweden.

The carbon sequestration analysis done with this model consists of two parts: first is a sub-model of CO_2 fixation and emission, and the second is to link this model to a long-range forest management planning model. This is described more in detail below based on Hoen & Solberg (1994).

Sub-model of CO_2 fixation and emission

The carbon flow related to a forest rotation is influenced by two processes: (1) the fixation process, and (2) the emission process. To model this flow one thus has to keep track of the biomass in living and dead trees.

Based on biomass functions provided by Marklund (1998), the biomass, measured in ton/ha, is calculated for each period both for the remaining stand and for the removals. The biomass is defined as the total biomass of a tree, consisting of needles, bark, living and dead braches, stem, stump, and root systems. Removals can be either natural mortality or harvests. The harvests can follow one of two cutting regimes: thinning or clearcutting.

Biomass growth in a period t is defined as the difference between the biomass of the remaining stand plus the biomass of the removals at the end of period t (i.e. at the start of period t+1) minus the biomass of remaining trees at the start of period t. Gross CO_2 fixation (ton/ha) in one period will then be the biomass growth multiplied with a factor F, where F = 0.5 x 44/12, as the carbon content in the biomass is assumed to be 50 percent (all trees in the world have a carbon content which is very close to 50 percent of the dry weight), while 44/12 is the relative weight of a CO_2 molecule compared to a carbon atom. CO_2 removal (ton/ha) in one period can then be computed as the biomass of the removal times the factor F.

Future CO_2 emission is a function of the decay rate, or the organic lifetime, of the removals. CO_2 emission are calculated for the removal in each time period separately and then summed for the removals from all time periods. The removal in each period is distributed into 14 different end use categories, with individual emission rates.

The total lifetime of carbon in biomass, removed from a stand, is divided in anthropogenic time and decay time. No decay is assumed to take place during the anthropogenic time, while the decay time is defined as the time it takes to decompose 90 percent of the biomass and release carbon as CO_2. End use distribution ratios and lifetime information are based on the current consumption patterns in Norway.

Integrating net CO_2 fixation and long-range forest management planning

The CO_2 fixation emission model is linked to a long-range management planning model, GAYA-LP. The model reported by Hoen (1990) and Hoen and Eid (1990), is based on simulation of treatment schedules for homogeneous stands and solution of the intertemporal forest management planning problem by linear programming.

GAYA-LP projects the development of a forest stand on a 5-year basis. The stand simulator module is used as a matrix generator to calculate the input/output coefficients related to each stand treatment schedule. The calculations are based on the existing forest growth data for Norway as described in Hoen (1990). The growth and yield functions in the stand simulator are at present not adjusted in order to reflect possible changes in future growth rates due to potential changes in the climate, but this can be done assuming one has empirical data on the growth changes caused by climate changes.

The present value of the flow of net timber payments is calculated according to a modified Faustmann’s formula. The economically efficient rotation ages, thinning intensities, and silviculture investments, are reached by optimization depending on tree species, interest rate, costs, timber price and site class.

Recently, the soil model YASSO has been added, so also soil GHG impacts can be included. YASSO is described above in Ch. 7.2.1.

Evaluation

This model`s main weak point is that it is not implemented in countries other than Norway (and to some degree Sweden). Its main strong points are:

- economic optimisation model,
- can incorporate rather detailed forest management alternatives,
- detailed soil model,
- can include other environmental aspects easily as constraints,
- can be used exogenously to give valuable input data for the forest growth model in EFI-GTM,
- can be further divided in sub-regions of a country if data allow.

6.4 Farm/property level

Both the above described models EFISCEN and GAYA-JLP can be used at property/farm level.

6.5 Forest stand level

6.5.1 CO2FIX

References

NABURRS, G.J., J.F. GARZA-CALIGARIS, M. KANNINEN, T. KARJALAINEN, T.LAPVETELAINEN, J. LISKI, O..MASERA, G.M.J. MOHREN, M. OLGIN, A. PUSSINEN & M.J. SCHELHAAS 2002. CO2FIXV2.0; manual of a model for quantifying carbon sequestration in forest ecosystems and wood products. Wageningen, Alterra, Green World Research. Alterra-report 445. 44p.

The model CO2FIX (latest version is CO2FIX 2.0) was developed by a research group coordinated by Alterra, Wageningen, Netherlands, and described in Nabuurs et al. (2002). It is a simple book-keeping model that converts volumetric net annual increment data (and additional parameters) to annual carbon stocks and fluxes of the forest ecosystem-soil-wood products chain. It calculates the fluxes for a forest stand unit of one ha which has to be specified according to standing stock volume, forest growth, stand density, mortality, specific weights, end-uses of fellings, etc.

The forest unit can be multi-species or uneven-aged, but homogeneous. Soil dynamics is included by using the YASSO model as described above in Ch. 7.2.1. The model can deal with many varieties of forest types like agro-forestry systems, selective logging systems, and post harvesting mortality. The software including input files can be downloaded from the world wide web at http://www.efi.fi/projects/casfor.

Evaluation

This model has as strong point in this project that it can give valuable exogenous input into the EFISCEN and GAYA-JLP models (and thus also into EFI- GTM) regarding volumes of roundwood production and carbon sequestration at a rather detailed description of forest stands/compartments. It has, however, no economic and regional/spatial components.

6.6 Comparative assessment of selected models

The selected models are evaluated separately in Ch..6.1-6.5. Table 2 gives a summary on the criteria used for agricultural models in Table 1.

The picture which emerges, is that EFI-GTM, EFISCEN (and CO2FIX when necessary) should be used in combination, so that the rather rough forestry model in EFI-GTM is supplemented (iteratively) with the more detailed forestry models EFISCEN and CO2FIX. In many ways GAYA-JLP would be better to use than EFISCEN, but because the former model at present is implemented only in one country, it is unrealistic to assume that EU-coverage will be possible in a 2-3 years perspective as the costs are likely to be too high.

Clearly, the use of EU agricultural land is at focus in the project. Forestry and forest industries can become a user of agricultural land which gives lower profitability than forestry, either for bioenergy production (short rotation forestry) or long rotation round-wood production. As such it is important that the agricultural models include the use of forestry short rotation crops as alternatives.

Through various CAP measures (and international agreements – not least those of the WTO) the value of agricultural land will change, and forestry (bioenergy and other assortments) can become profitable alternatives on some of this land, in particular if subsidies are introduced for e.g. biomass energy or carbon sequestration.

Through iterative interactions between the agricultural and forest models, one can determine the land economically available for forestry. Then EFISCEN and CO2FIX can be used to estimate the carbon sequestration impacts (and other greenhouse gas impacts) of the change in land use. Finally, the carbon impacts of the increased roundwood volumes supplied to bioenergy and forest industry markets can be analysed by using the EFI-GTM model.

This iterative modelling approach would secures consistency with changes in the CAP and other relevant policy measures. Furthermore, the procedure will be flexible as it can be improved in detailness according to data availability and policy makers demand for accuracy.

Table 2: Synopsis of Relevant Models Incorporating GHGE Mitigation Options and Forest Sector Carbon Sinks

Name of model or model framework	Developing Institution	Economic sub-model and/or data base	Focus of model	model scale	strengths	weaknesses	Consideration of GHG	
							carbon sinks	other GHG
EFI-GTM	European Forest Institute, Finland	FAO + own data collection	Economic and policy analysis of interna-tional forestry and forest industry issues	Global. Each country in Europe is one region 61 regions alto-gether	(1), (2), (3), (5), (6), (7),	(4), (5)	(-)	(-)
EFISCEN	European Forst Institute and Alterra	No econommic data. National Forest Stati stics	Forest growth and harvest	**Country**	(1), (2), (4) , (7),	(3), (5) ,(6)	(+)	(+)
GAYA- -JLP	Agric. University of Nor-way	Economic optimization model. Data from Na-tional forest inventory	Economic and policy analysis of harvest and silvicultural strategies	Country, regions of a country, and property level	(1), (3), (4), (5), (6), (7)	(2)	(+)	(+)
CO2FIX	Alterra, Wageningen	No economic data. Forest inventory	Growth and yield	Forest stand/compart ment	(1), (5), (7)	(2), (3), (4), (6),	(+)	(+)

(1) Production coverage **(2)** Regional coverage **(3)** Economic steering mechanism **(4)** Trade offs with environmental quality **(5)** Site specific effects **(6)** Allocation and distribution effects **(7)** Reputation and status of application of the model

(+) covered by the model **(-)** not covered by the model

7. Overview of existing combined agricultural and forest sector models

Currently there is no model approach available for the EU level that simultaneously considers the agricultural and the forestry sector. However, as mentioned in chapter 5.1, the carbon sink modelling system of the U.S. contains a combined agricultural and forest sector model. This approach will be described in the following.

7.1 Forest and Agricultural Sector Optimisation Model (FASOM)

References

ALIG, R.J., D.M. ADAMS and B.A. CARL (2000): Protecting Impacts of Global Climate Change on the U.S. Forest and Agricultural Sectors and Carbon Budgets. Paper presented at the boreal Carbon Conference (May 2000).
FOREST AND AGRICULTURAL SECTOR OPTIMIZATION MODEL: Model Description. In: http://agecon.tamu.edu/faculty/mccarl/mitigate.html
GILLING, D., B.A. MCCARL and R.D. SANDS (2002): Integrating Agricultural and Forestry GHG Mitigation Response into General Economy Frameworks: Developing a Family of Response Functions. In: http://ageco.tamu.edu/faculty/mccarl/931.pdf
MCCARL, B.A. (2002): A Guide to Running Alternative Scenarios with FASOM. In: http://agecon.tamu.edu/faculty/mccarl/FASOM.html

FASOM is a dynamic, non-linear programming model of the forest and agricultural sectors in the United States. It has been developed for the U.S. Environmental Protection Agency (EPA) to evaluate the welfare and market impacts of alternative policies for carbon sequestration by forestry and agricultural land use in a long-term prospective.

Within FASOM, the agricultural sector is represented by the ASM modelling system which was described in chapter 5.1. For the assessment of GHGE relevant to agriculture the ASMGHG model is used. For ASM to be integrated in FASOM the initially 63 regions within ASM are aggregated to 11 regions. The product differentiation of ASM is maintained in the aggregate.

The forest sector in FASOM consists of the following basic building blocks: (i) demand functions for forest products, (ii) timberland area and inventory structure and dynamics, and (iii) production technology and costs. The demand functions for the different forest products which are integrated into FASOM are derived from the results of other forestry models, like TAMM (Timber Assessment Market Model), NAPAP (North American Pulp and Paper) and ATLAS a Timber Inventory Model. Timber management decisions are endogenous in FASOM.

The optimisation procedure of FASOM is based on a non-linear programming approach, maximising the net present value of the sum of the consumer and producer surpluses for each sector. Producer surplus is interpreted as the net returns from forest and agricultural sector activities. Limitations of the FASOM approach result from the fact that it is working on decade time steps. This means that yearly agricultural production decisions have to be modelled simultaneously with long-term investment decisions in the forestry sector, which is a principle weakness of a simultaneous modelling approach for both sectors. But given this limitation, FASOM enables, in principle, to model the competition for land between agricultural and forestry timberland enterprises. Land transfer to and from agriculture can be analysed in a rather detailed way, distinguishing region, land class, type of owner, cover type, site quality, age of cohort of existing trees and management regime.

The modelling system is designed to work on the forest and/or agricultural sector either independently or simultaneously. This allows one to study sectoral issues either independently or across the two sectors.

On the basis of FASOM the following greenhouse gas sources and sinks from respective emission sources are captured:

- land use change (CO_2, CH_4, N_2O),
- change in management within a land use (CO_2, CH_4, N_2O),
- livestock management (CO_2, CH_4, N_2O),
- energy use within the sector (CO_2, CH_4, N_2O),
- biofuel production (CO_2).

Evaluation

The combined analysis of the agricultural and forest sectors and of all relevant greenhouse gases has been used to estimate the impacts of abatement options for these sectors in the U.S. Various climate protection policies can be simulated and assessed in isolation or policy packages. For instance, the contributions of agriculture and forestry resulting from articles 3.3 and 3.4 of the Kyoto protocol have been analysed. For varying carbon prices, land use change between the agricultural and the forestry sector and the resulting impacts on income distribution and general welfare have been simulated.

FASOM meets most of the evaluation criteria defined in this study. As can be concluded from the numerous references on FASOM, the modular structure is well suited to integrate other models or model results, especially with respect to different forestry models. But because of its time differentiation (decade time steps) it is less suitable for the analysis of the impacts of specific agricultural policy reform scenarios.

8. Proposed modelling approach with respect to carbon sinks and abatement strategies

8.1. Principle considerations and conclusions

1. The agricultural farms and forestry enterprises are the production units, which have to realise their contributions to carbon sinks. They may be the addressees of policy measures in form of direct regulations and indirect economic incentives. Therefore, a modelling concept for the analytical foundation of abatement strategies and the realisation of carbon sinks has to be based on modelling approaches for samples of agricultural farms and production units in the forestry sector, which take account of the relevant technical processes.
2. A modelling approach based on representative samples of farms and production units in the forest sector would be sufficient, if the envisioned measures with respect to carbon sinks would have only a marginal impact on production and market performance. In this case, it would be possible to estimate marginal abatement cost curves for different samples of farms and to aggregate them up to the Member State and EU-level.
3. Yet it has to be expected that a larger dimensioned strategy to reduce carbon sinks would have a significant impact on national and EU-markets (possibly in some cases even on world markets) for agricultural and forest commodities. Therefore, it is necessary to complement modelling approaches on the basis of farm samples and samples of forest enterprises by agricultural and for-

estry sector models, which are able to analyse the impacts of abatement and carbon sink strategies on national and international markets and the resulting feedback on agricultural and forest production.

4. The necessity to consider explicitly market impacts is especially of importance in the EU, because of pending further steps of CAP-reform under the influence of the WTO-process and the EU-enlargement. Further CAP reform might change the framework conditions for carbon sink strategies significantly. This would be especially the case when under the influence of a reduction of external and internal protection intensive forms of agricultural production would retreat from marginal areas in some parts of Europe, and afforestation would become more competitive.
5. The analytical conclusion is that the marginal abatement cost curves will be shifted under the influence of market feedback. The magnitude and the relevance of these shifts have to be analysed empirically. It can be expected that larger steps of CAP-reform will have significant impacts.
6. The conclusion for the overall modelling concept is that different types of modelling approaches should be integrated into an interacting modelling network. It should be based on sector models for agriculture and forestry, which are able to integrate the results of farm based models and of site specific analysis. The process based farm models have to be highly disaggregated in order to show e.g. the interaction between soil preparation techniques like ploughing versus minimum tillage with special herbicide application, and low input farming versus high input farming, with their impacts on carbon accumulation and GHG mitigation respectively. Farm simulation results as well as site specific information (e.g. from GIS-data) are to be transferred as exogenous data to the regionally differentiated sector models for agriculture and forestry. How this kind of models should be interlinked will be described in the next section.

8.2 Recommendations

The general conclusion from the principal considerations in section 8.1 and the assessment of existing models for agriculture (section 5) and forestry (section 6) is to establish a modelling network which is based on existing world wide modelling experience in this field, especially the FASOM modelling approach and to make use, as far as possible, of already existing empirical modelling work in the EU.

- The FASOM modelling approach can be very helpful for the design of the overall modelling concept, but would have to be modified for European conditions in the agricultural and forest sectors, as well as to the specific European policy situation.
- The rather far developed modelling systems for the agricultural and forest sectors in the EU should be used as a basis for the establishment of an integrated modelling system for the analysis of carbon sequestration strategies and the specification of contributions to the Kyoto Protocol.

8.2.1. Modelling systems for agriculture

Based on the previous discussion and evaluation of modelling work with respect to agriculture, the development of a carbon sinks simulation model for agricultural land is proposed, which should be complemented by process based farm models and site specific analysis:

- This model can make use of the longstanding agricultural sector modelling experience in the EU, but has to be extended by forestry activities on agricultural land, and amended by a system of carbon balances.

- Process based farm models for samples of farms have to contribute to the specification of the database for the sector model and are able to specify the impacts of policy measures with respect to specific technical processes and management strategies.
- Site specific models which are able to catch relevant physical interactions. GIS should be used for data provision.

Model for agricultural land

For the purpose of analysing the impacts of carbon sequestration strategies existing agricultural sector models have to be amended by:

- a set of forest production activities, which are suitable for afforestration on agricultural land. Appropriate activities have to be selected and specified with respect to input and output coefficients by forestry specialists.
- by a system of indicators, which balance the sources and sinks of greenhouse gases. These carbon balances have to integrate the results from process based farm models and of site specific analyses.

Process based farm models

The study has clearly shown, that agricultural sector models need support from process-based farm models. These are to be developed for representative farm types. Most of these models will be linear programming models that simultaneously optimise economic and ecological objectives on the farm level. Here also, existing model approaches should be preferred, as far as accessible. The model components with respect to sources and sinks of greenhouse gases have to be sufficiently disaggregated. This is necessary to take account of differences in farming intensity, feeding strategies, storage facilities, manure storage, and manure spreading techniques. Currently empirical research is only carried out in a few Member States, and the results are not for the whole EU. Therefore, we recommend to make use of the kind of process based farm models as they were developed by French and German researchers also in other Member States. This should be done as part of a concerted action according to the same methodological standards.

Site specific models

The role of soils that serve both as an emission source and sink of greenhouse gases, can either contribute to management strategies or work against them. This is particularly the case for soils with a higher than average N and C content. Site-specific models that simulate N and C dynamics on a small scale are available (DNDC, and CENTURY model). However, currently it appears to be difficult to use these approaches on larger scale level. Therefore, we recommend the assignment of distinguished research groups with the spatial representation and modelling of carbon sources and sinks and N_2O emissions of highly reactive soils and sites. Agricultural land uses as well as alternative forms of land use should be taken into account. Results from site-specific model approaches can then be transferred on the regional or EU-Member State level using GIS. It is recommended to concentrate only on sites, which are particularly relevant for emissions. If this should be too time and cost consuming, regression approaches, which are less detailed though, could be applied alternatively.

8.2.2 Modelling system for forestry

Based on the previous discussion and evaluation of the forestry and forest sector models, the following recommendation regarding the use of these models can be given:

1. The EFI-GTM and EFISCEN models should be used as basis for the development of a comprising forest sector model.
2. The CO2FIX model should also be used whenever necessary as input for the EFISCEN model.
3. The GAYA-JLP model should be used only if a larger follow-up project is foreseen, because the task of finding suitable growth functions (which has been done for the EFISCEN model already) will be rather demanding (it will require at least 3 man years of work). In the longer run, one should incorporate the GAYA-JLP model because of its strength in economic modelling and close connections to the less detailed forestry sub-model in the EFI-GTM model.

8.2.3 Integrated overall modelling approach

In summary the following overall modelling approach is suggested:

1. The model for agricultural land integrates the relevant results from process based farm models and site specific models. It will be used to analyse the greenhouse gas impacts of CAP-reform options as well as the impacts of specific carbon sinks enhancement strategies on environmental and agricultural objectives. The results can be used to estimate marginal abatements cost curves for measures applied to agricultural land.
2. The results of the model for agricultural land show also the impacts on land rent and the extent to which forest activities have substituted agricultural production and have contributed to carbon sinks. Also the impact of monetary incentives for afforestation can be analysed.
3. In a further step the forestry model will be applied to map the impacts of trend developments and policy impacts on forestry and forest industries (including bioenergy from forest) and the resulting impacts on carbon sinks.
4. In a final step, a modelling tool will have to be developed, which integrates the results of both models to get the total impacts for each set of agricultural and forest policy scenarios, as well as of specific carbon sinks strategies. This enables the derivation of marginal abatement cost curves for both, agricultural and forestry land.

This modelling approach would enable:

- to analyse simultaneously the impacts of specific carbon sink policies and of policy changes in other areas (CAP-reform, EU-enlargement, WTO-obligations, rural and environmental policies etc.)
- to monitor the impacts of realised policies on carbon balances, as a basis for political negotiations (e.g. in the Kyoto-process)
- and to create a basis for ex-post evaluation of pursued policies and further development of existing policies.

In addition to this policy oriented approach it is recommended to develop a long-term simulation model according to the FASOM approach as a complementary tool:

- which is designed to analyse the long-term impacts of alternative carbon sink strategies
- but which is not able to consider specific agricultural and environmental policy scenarios because of its high level of time-wise aggregation (dynamically linked decade models).

The complementary use of both types of modelling systems would help to get a better understanding of medium-term possibilities and long-term necessities.

Appendix 1

Overview of other existing models on different levels of scale

In the original proposal by EuroCARE for this study a number of other models and modelling systems on different levels of scale (world, EU, Member States) were mentioned. However, a more detailed analysis of these is not pursued anymore since these models do not meet the essential evaluation criteria. Another aspect is that some of these models were developed in other parts of the world on the basis of specific local conditions (data, location). This specificity makes a straightforward adoption to EU conditions difficult if not impossible. However, in order to provide a complete picture of available model approaches, the models not taken into account are discussed and evaluated only briefly.

A.1 World Models

All of the following examples are Computable General Equilibrium Models (CGE). The selected models treat agriculture generally as a separate sector. All of them include greenhouse gas emissions and are generally suitable to answer questions related to greenhouse gas emissions.

A.1.1 USDA (United States Department of Agriculture)

References

DARWIN, R. (1998): FARM – A global Framework for integrated Land use/Cover modelling. Working Papers in Ecological Economics No.: 9802, Australian National University.

The ERS (Economic Research Service) of the USDA uses the Future Agricultural Resource Model (FARM) which is based on the data from the GTAP model (Global Trade Analysis Project) developed and maintained at Purdue University. FARM is used to answer the following questions:

- world food security,
- trade agreements, e.g. effects of liberalisation on American agriculture and the environment (the latter is currently under development),
- global change: Analyses with respect to the effect of climate change and climate protection policies on agriculture are analysed with FARM.

FARM includes effects of climate change on land and water resources, agricultural production, international trade, and consumption. The model has an economic and an ecological model component. The latter consists of a Geographical Information System (GIS) which shows the effects of temperature and precipitation on land use and water resources. The economic module is a CGE based on the GTAP database. The most important aspects of the whole modelling system are climate, population, technologies and consumer preferences. Trade of 13 commodities between eight regions are modelled whereby the EU (as of 1990) counts as one region. Agricultural products are differentiated into plant products (wheat, other cereals and non-cereals), livestock and forestry products.

Evaluation

The USAD modelling system treats the whole of the EU as one region. The base year is 1990. The modelling system neither meets the requirements for a sufficient spatial differentiation nor can it be calibrated to current European agricultural statistics data. Nevertheless, the EU working group, which is to develop a collection of modelling approaches, should draw some valuable ideas from this model.

A.1.2 Multi-gas assessment of the Kyoto Protocol

References

REILLY, J. et al. (1999): Multi-gas assessment of the Kyoto Protocol. In: Nature, Vol. 401, S. 549-555.
PRINN, R. et al. (1999): Integrated Global System Model for Climate Policy Assessment – Feedbacks and Sensitivity Studies. In: Climate Change 41, Issue 3/4, S. 469-546.

The computations for the multi-gas assessment are based on the IGSM model (Integrated Global System Model for Climate Policy Assessment) which was developed by MIT (Massachusetts Institute of Technology).

ISGM consists of the Emission Prognosis and Policy Analysis model (EPPA). It is based on GREEN (General Equilibrium Environmental Model) developed by the OECD. Altogether 12 producing sectors and 4 consumption sectors are included, whereby agriculture is treated as a separate production sector. It is differentiated between 12 regions, and the EU is taken to be one region. EPPA can be coupled with a number of other models, such as atmospheric chemistry and climate models as well as various models of terrestrial and oceanic eco systems.

Evaluation

This model also treats the EU as one single region. With respect to the objective of this global system model this is appropriate. Regarding the EU objective for this study the critique is the same as for the USDA model.

A1.3 Global trade model of the OECD

References

BURNIAUX, J.-M. (2000) : A Multi-gas assessment of the Kyoto Protocol. ECO/WKP(2000)43. OECD.

The model GREEN (General Equilibrium Model) was developed and used by the OECD. Green includes agriculture as a separate sector, which is further distinguished into animal production, rice production, and other agriculture. With respect to non-CO_2-emissions, N_2O emissions from fertilisers, CH_4 emissions from rice production, and ruminant CH_4 emissions are considered for agriculture. IGSM also provides interfaces for results from IGSM.

Evaluation

For this model the same critique applies as for the last two models.

A.1.4 GTEM (Global Trade and Environmental Model) at the ABRARE (Australian Bureau of Agriculture and Resource Economics)

References

BROWN, S. et al. (1999): Economic impacts of the Kyoto Protocol. ABRARE project 1590. ABRARE Research Report, 99.6.

GTEM is a global trade and environment model. It consists of the models MEGABARE and GTAP. GTEM does not only integrate energy related CO_2 emissions, but also non-energy related CO_2 emissions, CH_4 and N_2O). In GTEM, 18 different regions are considered, and again the EU is treated as one region. GTEM takes account of the global trade of 23 products. Agricultural products and related greenhouse gas emissions are further distinguished into:

- rice (energy related CO_2 emissions, CH_4, N_2O),
- cereals (energy related CO_2 emissions, N_2O),
- non-cereals (energy related CO_2 emissions, N_2O),
- animal production (energy related CO_2 emissions, CH_4, C_2O),
- forestry and fishery (energy related CO_2 emissions).

Evaluation

GTEM is a global trade and environmental indicator model, which is, rather disaggregated with respect to agriculture, but again treats the EU as one single region. Just as with the global models mentioned above it cannot be justified that the EU region is disaggregated for the model to meet the evaluation criteria.

A.1.5 ICLIPS (Integrated Assessment of Climate Protection Strategies)

References

KLEPPER, G. and K. SPRINGER (2000): Benchmarking the Future: A Dynamic, Multi-Regional, Multi-Sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper No. 976.
DEKE, O. et al. (2001): Economic Impact of Climate Change: Simulation with a Regionalized Climate-Economy Model. Kiel Working Paper No. 1065.
LEIMBACH, M. et al. (2000): ICLIPS - Integrated Assessment of Climate Protection Strategies: Political and Economic Contributions. Potsdam Institute for Climate Impact Research, Research Report No. 296 41 815.

Under the direction of the Potsdam Institute for Climate Impact Research leading international researchers of different disciplines have developed an integrated model network to assess climate protection policies. In this approach, ecological, geo-biophysical, climate and socio-economic models are interlinked in a conceptual network. As for the socio-economic model the model DART (Dynamic Applied Regional Trade) developed by the Kiel Institute of World Economics was employed among others. DART is a recursive dynamic CGE Model which was calibrated on the basis of the GTAP database. It models 10 sectors and 11 regions. The whole of Western Europe is taken to be one region. Agricultural production is identified as unprocessed rice, processed rice, cereals, non-cereals, wool, dairy products, meat products, other livestock, other food, forestry, and fisheries. Another model was employed to project long term economic growth.

Evaluation

This model which was developed by a number of German research institutes takes account of the agricultural sector in the sense that it is disaggregated with respect to the most important emission sources. The whole of Western Europe is taken as one region. However, because of this compatibility with policy options of the EU cannot be sufficiently guaranteed.

A.1.6 ZEW (Center for European Economic Research)

References

BÖHRINGER, C. (1999): Cooling Down Hot Air. A global CGE Analysis of Post-Kyoto Carbon Abatement Strategies. ZEW Discussion Paper No. 99-43.

BÖHRINGER, C. and T.F. RUTHERFORD (2000): Decomposing the Cost of Kyoto –A Global CGE Analysis of Multilateral Policy Impacts. ZEW Discussion Paper No. 0-11.

ZEW has carried out a number of model calculations with respect to effects of climate protection policies for energy related CO_2 emissions. Some of the studies were carried out together with external researchers involved in climate modelling, such as Prof Dr. Heinz Welsch of the Institute of Economics at the University of Oldenburg. More recent model calculations employ the GTAP-E models. In addition to the general GTAP database on economic and trade data GTAP-E includes the OECD/IEA energy statistic for 45 regions and 23 sectors. In this sub-model, agricultural products are included as 'trade margins' a single product group. The agricultural sector is not considered. The European Region includes the EU 15 and the EFTA. In order to assess climate change policy with respect to agriculture, the CGE model would have to be expanded.

Evaluation

Within the ZEW model agriculture is included as a sub-model. However, it is not sufficiently disaggregated with respect to plant and livestock production. Incorporating carbon sinks into the model would only be possible with considerable effort.

A.1.7 General evaluation of world models

From the individual evaluation of world models it follows that they are altogether suitable in principle, e.g., for the determination of marginal abatement costs under simultaneous consideration of interdependencies between sectors. Yet with respect to agriculture and forestry the process analytical specifications and the regional differentiation are rather basic and coarse. Hence, the use of those models to provide policy relevant information for policy makers cannot be recommended as stand-alone tools.

A.2 EU-level

A.2.1 GAPsi at FAL (Federal Agricultural Research Centre)

References

KLEINHANß, W. (2000): Betriebsgestützte Sektormodellierung oder sektorkonsistente Betriebsmodelle. Wohin steuert die Betriebsmodellierung. Online-Informationen des Instituts Institut für Betriebswirtschaft, Agrarstruktur und ländliche Räume der FAL.

The partial equilibrium model GAPsi (Model to Simulate the Common Agricultural Policy) was developed by the Institute of Market Analysis and Agricultural Trade Policy of the German Federal

Agricultural Research Centre. It has been applied to a large number of questions related to the analysis of agricultural markets. Altogether 13 agricultural products are considered (wheat, maize, other cereals, oil seeds, legumes, potatoes, sugar, milk, beef, mutton, pork, chicken, eggs). Besides the individual EU-Member States, three further regions (four CEEC countries, five main export countries, rest of the world) are distinguished.

Evaluation

This model was developed by the German Federal Agricultural Research Centre, Braunschweig-Völkenrode, on the basis of a model system initially developed at the University of Bonn. The model is specifically designed for agricultural policy analysis. Besides the individual EU-Member States three other regions, four Middle and Eastern European Countries, five of the main exporting countries for agricultural commodities, and the rest of the world, are considered. With respect to environmental indicators the model is less disaggregated than the similar model of the CAPRI project.

A.2.2 CEEC-ASIM (Central and Eastern European Countries Agricultural Simulation Model) at IAMO (Institute of Agricultural Development in Central and Eastern Europe)

References

FROHBERG, M. et al. (2001) : Auswirkungen der EU-Osterweiterung auf die Beitrittsländer - Analyse unter Berücksichtigung der WTO-Verpflichtungen. Tagungsbeitrag auf der 41. Jahrestagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaus e.V., 8. bis 10. Oktober, Braunschweig.

WEBER, G., O. WAHL und E. MEINLSCHMIDT (2000): Auswirkungen einer EU-Osterweiterung im Bereich der Agrarpolitik auf den EU-Haushalt. IAMO Diskussionspapier Nr. 26.

CEEC-ASIM is a partial static equilibrium model for the agricultural sector of middle and eastern European countries. The model consists of ten country models, one for each candidate country, which are not substantially different in structure but rather in technical parameters. It analyses the supply of agricultural products and the demand for foodstuff. Furthermore, the agricultural use of upstream products and labour is accounted for. Databases are the national statistics of the candidate countries. The model is used for comparative static analyses. The model assumes unlimited competition on the markets and the availability of complete information to all partakers in the markets. In accordance with these assumptions all supply and demand decisions are carried out following the marginal productivity and marginal utility principles. Model components for the quantification of agriculture born greenhouse gases are not yet incorporated in CEEC-ASIM.

Evaluation

So far CEEC-ASIM is the only modelling system for agricultural policy options in ten Middle and Eastern European Countries. It is based on rather scarce data sources from national statistical offices of the candidate countries. The analysis is comparative static. Greenhouse gases are not included since the model was developed to serve other purposes. However it could be examined whether it is possible to include greenhouse gas emissions on the basis of the IPCC factors in a simplified manner. This could offer at least some guidelines as to policies on greenhouse gas emissions in candidate countries.