Forschungsbericht 12/2011 [EN]

Agriculture as Emission Source and Carbon Sink: Economic-Ecological Modelling for the EU-15

Daniel Blank

Universität Hohenheim
Institut für Landwirtschaftliche Betriebslehre
Fachgebiet: Analyse, Planung und
Organisation der landwirtschaftlichen Produktion

University of Hohenheim
Institute of Farm Management
Department: Analysis, Planning and
Organisation of Agricultural Production

Daniel Blank:

Agriculture as Emission Source and Carbon Sink:
Economic-Ecological Modelling for the EU-15

Prof. Dr. Drs. h.c. Jürgen Zeddies, Institute of Farm Management, Department: Analysis, Planning and Organisation of Agricultural Production, University of Hohenheim (Publisher), Agrarökonomische Forschung – Agricultural Economic Research, Forschungsbericht 12/2011.

ISSN 1862-4235

Prof. Dr. Drs. h.c. Jürgen Zeddies
Institute of Farm Management
Department: Analysis, Planning and Organisation
of Agricultural Production
University of Hohenheim, 70593 Stuttgart, Germany.
e-Mail: zeddies@uni-hohenheim.de

Printed in Germany.

Druck: F. u. T. Müllerbader GmbH
Forststr. 18, 70794 Filderstadt, Germany

The research papers published in this series intend to encourage the discussion amongst scientists, practitioners, and political decision makers. The paper on hand is a dissertation which first contributed to the EU funded INSEA (Integrated Sink Enhancement Assessment)-project and was then furthered at the University of Hohenheim. Prof. Dr. Jürgen Zeddies and Prof. Dr. Harald Grethe of the Hohenheim University have been the reviewers for this work.

Aus dem Institut für Landwirtschaftliche Betriebslehre

Universität Hohenheim

Fachgebiet: Analyse, Planung und Organisation der
landwirtschaftlichen Produktion

Prof. Dr. Drs. h.c. Jürgen Zeddies

Agriculture as Emission Source and Carbon Sink: Economic-Ecological Modelling for the EU-15

Dissertation
zur Erlangung des Grades eines Doktors
der Agrarwissenschaften

vorgelegt

der Fakultät Agrarwissenschaften

von

Daniel Blank

aus Wangen im Allgäu

2010

Die vorliegende Arbeit wurde am 15. April 2010 von der Fakultät Agrarwissenschaften der Universität Hohenheim als „Dissertation zur Erlangung des Grades eines Doktors der Agrarwissenschaften“ angenommen.

Tag der mündlichen Prüfung: 20. Dezember 2010

1. Prodekan: Prof. Dr. rer. nat. Andreas Fangmeier
1. Prüfer, Berichterstatter: Prof. Dr. Drs. h.c. Jürgen Zeddies
2. Prüfer, Mitberichterstatter: Prof. Dr. Harald Grethe

Weiterer Prüfer: Prof. Dr. Manfred Zeller

Danksagung

An erster Stelle möchte ich meinem Doktorvater, Herrn Prof. Zeddies, für seine Unterstützung während der gemeinsamen Zeit an der Universität Hohenheim aber auch während der Zeit danach bis zur Fertigstellung der Dissertation danken. Herr Prof. Zeddies verstand es stets innerhalb des im Rahmen einer selbständigen, wissenschaftlichen Arbeit notwendigen Freiraums entscheidenden Einfluss auf deren Richtung zu nehmen.

Daneben habe ich die manchmal auch längeren Diskussionen und die guten Anregungen mit meinen damaligen Kollegen und Freunden in guter Erinnerung behalten. Vor allem Elisabeth, Nicole, Steffen, Michel und Herr Dr. Litzka möchte ich an dieser Stelle danken. Elisabeth möchte ich darüber hinaus meinen Dank für die kritische Durchsicht der Dissertation und die strukturellen Verbesserungsvorschläge aussprechen. Insgesamt trug das durch alle, auch die hier nicht genannten Freunde und Kollegen, geschaffene Umfeld sicherlich ein Übriges zum Gelingen der Dissertation bei.

Meinen Eltern gilt mein Dank dafür, dass sie mir zu Beginn der Promotion, als es galt sich für diesen Weg zu entscheiden, zur Seite standen und dass sie mich auch durch die lange Zeit der parallelen Arbeit in Beruf und an der Dissertation motiviert und begleitet haben. Dies gilt auch für meine Schwester, die es immer verstand mich in kurzer Zeit neu motivieren.

Ferner auch ein gracias an meine Freundin, die vor allem den Teil der Promotion miterlebte bei dem es galt auch an Wochenenden Zeit und Herzblut vor dem Rechner einzusetzen. Vielen Dank für das aufgebrachte und glücklicherweise nie ganz aufgebrauchte Verständnis.

Table of Contents

List of Abbreviations

Physical Units

°C	degrees Celsius
°K	degrees Kelvin
J	Joule
kg	kilogram
dt	deciton
toe	tons of oil equivalents
ktoe	kilotons of oil equivalents
Mtoe	million tons of oil equivalents
Wh	Watt hours
kWh	Kilowatt hours
MWh	Megawatt hours
GWh	Gigawatt hours
pH	potential hydrogenii
ppbv	parts per billion by volume
ppmv	parts per million by volume

Chemical Abbreviations

C	carbon
CO_2	carbon dioxide
CH_4	methane
N_2O	nitrous oxide
NH_3	ammonia

Standard Abbreviations

thd.	Thousand
Mill	million
Bill	billion
d	day
a	year (lat. annum)
ct	cent

Other Abbreviations

CVT	conservational tillage
EPIC	Environmental Policy Integrated Climate (formerly Erosion Productivity Impact Calculator)
EU	European Union
EU-EFEM	EU-Economic Farm Emission Model
FADN	Farm Accountancy Data Network
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GHG	greenhouse gas
GIS	Geographical Information System
HRU	Homogenous Response Unit (as defined by EPIC)
INSEA	Integrated Sink Enhancement Assessment (EU financed research project)
IPCC	Intergovernmental Panel on Climate Change
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
LU	livestock unit
LULUCF	Land use, land use change and forestry
lat.	Latin
n.a.	not available/ not applicable
NUTS	Nomenclature des Unités Territoriales Statistiques
SGM	Standard Gross Margin
SOC	soil organic carbon
UAA	Utilised Agricultural Area
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

List of Tables

List of Figures

Basic Definitions

The following definitions are valid within the current study and as such do not reclaim general validity.

Sequestration: Sequestration, here applied in the context of soil carbon sequestration, refers to a continuous increase in carbon stocks. This study is based on an annual modelling approach and long-term dynamics are not simulated. On a practical level, the permanence of carbon stocks would have to be verified continuously, since external shocks to carbon stocks are multiple. The term "sequestration" will only be utilised in cases where its application has become usual.

Accumulation: Accumulation, here applied in the context of carbon accumulation, refers to a situation in which the carbon stock is increased. The term "accumulation" will be utilised where sequestration does not fit. Initial baseline dynamics, like initial freeing, are disregarded.

Mitigation: Mitigation refers to the sum of a situation with and without an emission reduction measure. It is applied in the context of soil carbon and carbon dioxide and thus is also concerned with the baseline dynamics.

Mean Value: In the presentation of the study's results, mean value will be applied in contrast to average value. It refers to the unweighted average values over several regional results.

Average Value: In the presentation of the study's results, average value will be applied in contrast to mean value. It refers to the weighted average values over several regional results. The weighting factor thereby is the area represented by each region.

Reference Situation: In a simulation model reference situation refers to a point in time (or period) which represents the initial point (or period) to which scenario results are compared. This point in time (or period) usually lies in the past in order to validate statistical data against it and thereby validate the model. In the current study, the reference is the year 2003. The reference situation is free of scenario assumptions.

Baseline Situation: Baseline situation, in contrast to reference situation, describes a scenario specific reference in which scenario obligations are not in place. However, in contrast to reference situation, certain scenario specific assumptions can apply and make the baseline result differ from the reference situation.

1 Introduction

While years ago the discussion about climate change still had a fundamental character and it split participants into a group denying human induced climate change and a group predicting threatening scenarios for our planet in which one climate extreme would chase the next one, the current picture is painted by carbon trade. The Kyoto Protocol has been put into force and emission reduction compliance has thus become true for most of the developed countries world-wide that passed on some of their emission reduction compliance to energy intensive sectors of their national economy. The Kyoto Protocol provides in the form of three flexible mechanisms for cost efficient means to reduce greenhouse gas emissions while supplementary action is taken by voluntary initiatives through which airlines offer to clients balancing their flight emission with emission reduction certificates from climate protection activities. Thereby the concept and magnitude of the Kyoto Protocol are unique and the first of their kind. Never before, environmental goods had been priced in a multinational agreement and pollution (beyond a permitted level) been fined.

The quantification of allowed emissions and committed emission reductions, a task so fundamental to functioning carbon markets, is relatively easy in industries or sectors where emissions occur at stacks or similar “hot spots”. In other industries or sectors like agriculture or forestry where emission sources are multiple and disperse, quantification is by far more complex. Apart from this monitoring issue, agriculture and forestry could take a decisive position in climate change mitigation. This is due to the fact that they potentially act as emission source and as carbon sink. Further, their nature is appropriate for fast and immediate climate action often demanded by scientist to cut the peak of atmospheric greenhouse gas concentration.

In agriculture a larger share of emissions is attributable to land use and land use change rather than to agricultural production itself. In terms of global emissions, the land use change due to agricultural activities is estimated at 18%, while agricultural production is estimated at another 14% (vTI, 2008). A comprehensive climate strategy on agriculture thus should cover both aspects. Apart agriculture can provide renewable fuels that can be utilized to switch fossil fuels thereby avoiding the emission of carbon dioxide to the atmosphere. However, agricultural bio-energy production is accompanied by controversies about its price driving force on conventional agricultural commodities and by the food versus fuel discussion.

1.1 Problem Description

From the perspective of agricultural research, the quantification and the assessment of the emission source and the carbon sink function of agriculture for a wide geographical area is of first priority. Agricultural emission sources thereby involve fertilizer application, enteric fermentation (ruminants), and soil emissions. Soil emissions do not restrict to, but can include the release of soil carbon. The agricultural source function significantly contributes to global anthropogenic emissions. In the reverse, the agricultural sink function consists of the inclusion of atmospheric carbon (dioxide) to soils.

Now, agricultural GHG emissions have already been quantified and mitigation strategies in conventional production have already been assessed for different geographical areas. In the analyses different kinds of models have been applied involving market and programming models. Yet an integrated approach that would assess also new production alternatives like bio-energy while taking into account policy framework, cross-sectional links, and inter-regional trade over time does not yet exist (SCHMITZ et al., 2009). Although market models do simulate trade and can potentially simulate cross-sectional links, programming models on farm level could serve to deliver valuable results on the adaptability of different farm types or on bio-energy production and farm-level decisions could be simulated accurately. Also programming models for the EU exist. The wide geographical coverage, however, has been on the expense of the level of detail.

For micro-economic programming models, the reason why EU-coverage and a high level of detail could not be fitted together, so far, is to be seen in predominantly in the substantial data need of such models in terms of ecological and economic coefficients. To overcome this obstacle, in emission accounting often default values are utilized, which, however, especially when it comes to depict complex biological processes only are a strong simplification of reality. Here, biophysical models are available and are more appropriate. Integrating simulation results of biophysical model into programming models is an interesting research topic. Concerning the second major data area, the economic coefficients, default values for European agriculture do not exist. This applies mainly to cost values since revenue values are reflected in prices and usually known. The economic coefficients are crucial and their quality will widely decide on the quality of the applied programming model.

In this study a programming model for the EU-15 will be developed and applied. Apart from the mentioned barrier of significant data need, the development of the model was done considering the requirements of the Integrated Sink Enhancement Assessment (INSEA)-project, a project in which the model found its first application. The INSEA-project was financed by the Sixth Framework Program of the European Commission and it follows an integrated approach unifying several sector models and model approaches to simulate the carbon sink function of agriculture and forestry and to economically assess mitigation scenarios.

1.2 Objectives

The first application of the model developed within this study was in the INSEA-project. The goal of the INSEA-project was "(…) to develop an analytical tool to assess economic and environmental effects for enhancing carbon sinks on agricultural and forest lands." (OBERSTEINER, 2003, p.3) The focus was neither restricted to carbon sinks nor to carbon but it rather involved the entire basket of biogenic greenhouse gases and the climate impacts from food and biomass production. INSEA was conceived to support the formulation of policy options that "(…) allow cost efficient and practical implementation mechanisms for LULUCF (Land Use, Land Use Change and Forestry)[1] activities, taking into account other international conventions [,e.g. on biological diversity accorded within the so-called Helsinki Process]." (OBERSTEINER, 2003, p. 5).

The objectives of the present study, which partially integrate the INSEA-goal, can be summarised as follows:

---

[1] LULUCF in contrast to the also common LUCF includes the current land-use, i.e. carbon from the current land-use is also considered.

a) *Development of analytical tools for modelling the agricultural production in the EU-15:*
This objective partially has already been achieved by other studies. Here, a more detailed analysis of animal and plant production involving alternative soil management practices is targeted at;

b) *Integration of analytical tools for modelling activity based agricultural GHG emissions:*
It is sought to integrate different GHG-accounting methods, to be used alternatively, prioritizing IPCC default values;

c) *Estimating regional agricultural production costs for the EU-15:*
It is sought to estimate variable production costs, necessary to calculate gross margins of simulated production activities, on regional level, here NUTS-II. Provided this objective can be achieved, a great hurdle in the development of any agricultural micro-economic model in the EU would be passed;

d) *Quantification of carbon sequestration potentials of agricultural soils by integrating spatially explicit data:*
The integration of spatial explicit data from biophysical simulation models into the economic framework of the study model is difficult, but the expected gain in accuracy justifies this effort. Alternatively available default values on soil carbon dynamics cannot capture the diversity of determinants (soil type, climate, etc.); and

e) *Economic and ecological assessment of biomass to bio-energy potentials and other agricultural scenarios mitigating climate change:*
The objective is to deliver scenario results for the EU-15 on biogas production and carbon sequestration taking into account agricultural policy.

1.3 Methodology

Due to the multitude of objectives aimed at by this study, the approach applies various methodologies. At its core stands the simulation within an economic-ecological programming model. The model is of the type mixed-integer and it maximizes total farm gross margin. The farms as smallest modelling unit reflect the main dividing characteristics of farm types as categorised by an official EU source.

Simulating farm types it is possible to mimic farm level decisions like political programs or to describe scenario impacts according to the farm structure.

Although the utilized programming model evolves from predecessor versions, a new methodology to estimate variable production costs had to be developed. This is due to the geographical expansion of the model from three German provinces to the EU-15. Originally, engineering cost data was applied. For Germany such data is available in good quality. For Europe comparable data is not accessible. To overcome this gap, a methodology was developed that combines the original German engineering cost data with European accountancy data.

With this study the developed model was not only expanded over previous versions, but also site-specific data on soil organic carbon were integrated from a biophysical model. Soil organic carbon dynamics depend on a number of natural conditions that could not have been simulated at similar quality and at justified effort in the applied economic-ecological model. The linkage created between both models demanded for an interface transferring the data from different geographical resolutions and different origin.

The enlargement of the model and the linkage to other model types besides the formulation of new production activities like biogas required also the development of a new database structure and finally ended up in the application of a new programming language.

Although the significantly widened geographical coverage in comparison to former model versions, the widened research scope with further production alternatives, and the inclusion of site-specific data into the model, the illustrative means are selected as best compromise between expressiveness and detail. This principle is followed throughout the entire study.

2 Climate Change and Agriculture

In its narrow sense, climate describes the “average weather” in a certain area. Drawing this average weather the reference period should be spanned wide enough to reflect typical local conditions at sufficient accuracy. The World Meteorological Organization (WMO, 2007) defines the classical reference period as 30 years. In its wider sense, climate describes the climate system comprising of the constituents atmosphere, hydrosphere, cryosphere, land surface, and biosphere, and the interactions among them. Climate variability is natural because of internal dynamics and external forcing like volcanic eruptions. Climate change, in contrast, is the “[…] change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UNFCCC, 1992, Background).

Agriculture is a sector that widely depends on climate and thus is also vulnerable to weather phenomena entailed by climate change. When talking about the contribution of agriculture to climate change in the form of greenhouse gas emissions or as carbon sink thus only one direction of the interaction between climate and agriculture is mentioned. In the other direction, agriculture is affected by changing climate affecting plant growth or animal health. In this study the impact of climate change on agriculture is not simulated. Although climate change is perceived to be already present, climate change is comparatively slow and the regional manifestation is unclear. Due to the present study simulating yearly production periods and uncertainties on the development of major input factors like agricultural prices, it is renounced to simulate uncertain effects of climate change on agricultural productivity. The number of climate scenarios painted by scientists and their impacts on plant growth, animal health, and so on are so diverse, that it seems to be the most accurate to assume constant climate conditions for the scope of the model which is that of 2013.

2.1 Greenhouse Effect

If we ask ourselves why the earth’s average temperature is just in a comfortable range between the boiling and freezing point of water, the answer cannot simply be that the distance between the earth and the sun is just optimal. It is also because of the greenhouse effect. Both circumstances together have made the global mean (ground) temperature settle at around +15°C. If the greenhouse effect were not present, during the absence of solar radiation at night the atmosphere would rapidly cool down and heat would not be retained during daytime. As a result, the global mean temperature would be below -15°C.

Our atmosphere guarantees a moderate heating effect by letting visible sunlight reach the earth's surface and partially reflecting outgoing radiation back to the earth's surface. The reflection is principally of long wave infrared radiation, which is warm radiation (for details see KIEHL and TRENBERTH, 1997). The majority of gases that constitute our dry atmosphere (nitrogen, oxygen, and argon (78.0%, 20.9%, and 0.93% volume mixing ratio)) do not interact with solar radiation. This is not true for atmospheric trace gases (IPCC, 2001). With respect to the insulating effect of the atmosphere, trace gases compare to the glass walls of greenhouses. The relevant major trace gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Apart from these trace gases, there are trace gases that are available in minor concentration but have gained notoriety for their harmful effect on the ozone layer like the chlorofluorohydrocarbons. Despite of constituting major determinants in the greenhouse effect, the concentration of the trace gases is very low (water vapour 1.0%, all other trace gases together 0.1%).

Natural incidents like volcanic eruptions, and the presence of water in its different phases, influence trace gas concentrations vastly and ultimately also climate. Although the manifold contributors, the unknowns, and the interactions, trace gas concentrations do not fluctuate too much since sources and sinks equilibrate each other. Since the beginning of industrialisation in 1750, however, there has been a measurable increase in the mixing ratios of atmospheric trace gases (see Table 1). In other words, the natural equilibrium between sources and sinks has been perturbed by anthropogenic activities. “The rate of increase [in CO_2-concentrations] over the past century is unprecedented, at least during the last 20,000 years.” (IPCC, 2001, section C1)

Table 1: Atmospheric Greenhouse Gas Mixing Ratio and Rate of Increase

Gas	**Pre-Industrial Ratio**	**Ratio in 2000**	**Rate of Increase**
	(ppbv)	(ppbv)	(%)
CO_2	0.280	0.367	30
CH_4	750	1,745	50
N_2O	275	316	17

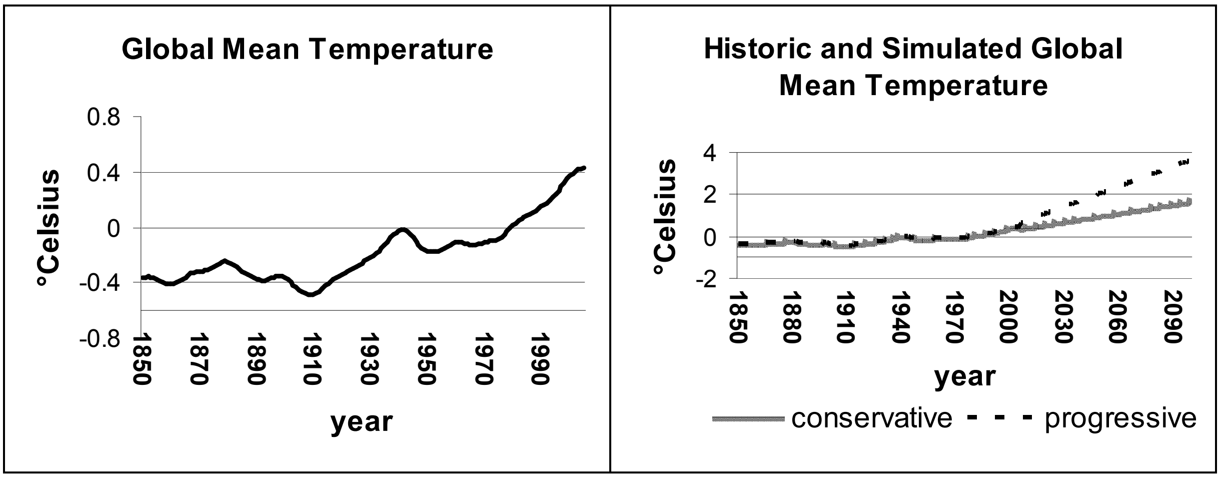
Source: IPCC (2001)

On one hand, the rise in trace gas concentrations can be traced back almost exclusively to human activities. “Most of the emissions during the past 20 years are due to fossil fuel burning. The rest (10 to 30%) is predominantly due to land-use change, especially deforestation.” (IPCC, 2001, section C1) Land-use change due to deforestation, irrigation, urbanisation, etc. changes the physical and biological properties of the land surface and it changes natural carbon reservoirs and ultimately affects the climate system. Forest clearing and agricultural practices each contribute about 15% to anthropogenic climate warming (UMWELTBUNDESAMT, 1994).

On the other hand, there are counteracting, smoothing processes which can be found in the sink function of oceans and soils and in the limited lifetimes of trace gas molecules in the atmosphere (e.g., methane reacts with hydroxyl-ions). Aerosols dampen the greenhouse effect by extenuating solar radiation. Aerosols, which are small particles, usually drop out of the atmosphere after several days (IUC, 1999). They develop naturally but also from anthropogenic activities like the emission of sulphurous dioxide from power stations or from burnt plant residues.

When comparing the insulating and warming effect of trace gases, i.e. their radiative forcing, large differences appear. Reference value is the warming effect of carbon dioxide; in quantities the most important greenhouse gas. Apart from the considered gas, a main variable of the warming effect is also the reference horizon since the lifetime of the molecules in the atmosphere are different for the gases. The lifetime of carbon dioxide varies between 5 and 200 years, depending on the rates of uptake and removal processes. The lifetime of methane is 12 years (scission with OH^--ions in the air) and 114 years for nitrous oxide. The parameter defined by the IPCC is the Global Warming Potential (GWP). A common reference horizon of 100 years of lifetime is practical, expressed in the parameter GWP_{100}. By 2001, the IPCC recommendation for the GWP_{100} was: CO_2 1, CH_4 23, and N_2O 296 (IPCC, 2001).

Simultaneously with the increase in mixing ratios of trace gases, a rise of global mean temperatures has been recognised. On a global average, land-surface and sea-surface temperatures rose by 0.3 to 0.6°C between the late 19th century[2] and 1994 (IPCC, 2001) (see Figure 1, left). For the year 2100, climate models predict a temperature rise of 1.5 to 3.5°C in comparison to the current level (see Figure 1, right). The rise in temperatures is just one in a chain of expected climate impacts. Increased evaporation has also been predicted, entailing rainfalls increasing by one percent in the high, mid, and most equatorial latitudes, while decreasing in most sub-tropical zones (Carter and Hulme, 1999). Extreme weather events like droughts are likely to occur more frequently (for details see Umweltbundesamt, 2006). All these predictions, however, adheres a large level of uncertainty due to the climate system's complexity and the numerous interactions of processes. Large share of the uncertainty is attributable to feedback reactions. An example of such feedback reactions is snow covered areas. These normally reflect solar radiation, thus hindering the soil from warming up and ultimately dampening the greenhouse effect. If the snow cover melts away, as a result of increased temperatures, then self-accelerating climate warming is initiated.



Sources: left: IPCC (2001); right: IUC (1999)

Figure 1: Climate Warming (Anomaly in °C relative to 1961 to 1990)

In assessing climate impacts some could be tempted to see increased mean temperatures as positive, at least for the densely populated temperate zones. Such or similar evaluations would, however, be too hasty, because they neglect adaptation costs and negative externalities. Schnellnhuber (2006) from the Potsdam Institute

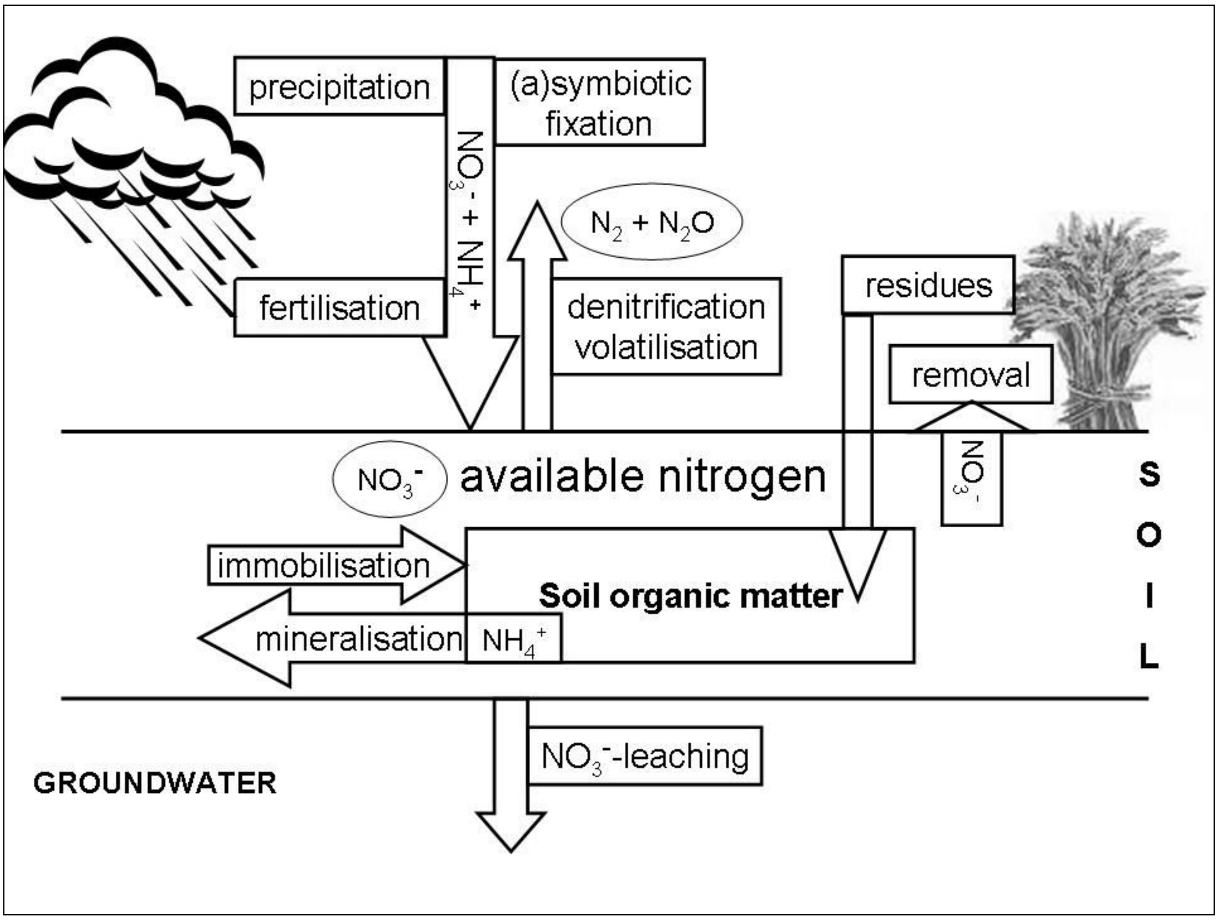
---

[2] Regular temperature measurements have only been executed since 1860.

for Climate Impact Research writes the overall global economic costs of climate change are between 5 and 10% of the global gross domestic product. He opposes costs of climate protection at 0.5% of the global GDP, which would inhibit global mean temperatures from rising by 2°C during the next decades: equal to a stabilisation of current mean temperatures. “An estimate of resource costs suggests that the annual costs of cutting total GHG to about three quarters of current levels by 2050 […] will be in the range -1.0 to +3.5% of GDP, with an average estimate of approximately 1%.” (STERN, 2006, p. 211) The cited authors admit there is a high intrinsic uncertainty in their estimates that stems from unpredictable human behaviour with respect to readiness for lifestyle adaptations, and from the research deficit in this field.

2.1.1 Agriculture and Nitrous Oxide

In the year 2000, 65% of all nitrous oxide emissions in the EU-15 were of agricultural origin (DUCHATEAU and VIDAL, 2003). The main sources are soils and manure management. A minor source is burning of crop residues. Soils and manure management contribute around 87% and 13% to nitrous oxide emissions from agriculture in Europe. Burning of crop residues contributes 0.2%.



Source: based on KRAYL (1993)

Figure 2: Simplified Nitrogen Cycle

Apart from burning, emissions of nitrous oxide are via the intermediary step of nitrogen mineralisation in the form of NH_3 / NH_4^+. This can be followed in Figure 2 where the different molecular presences of nitrogen in the atmosphere, fertilizers, biosphere, and soil, as well as in the sub-systems involved in the nitrogen cycle are illustrated. Soils are enriched in plant available nitrogen via the processes of mineralisation of organic material, biological fixation, atmospheric deposition, and fertilisation. A loss of plant available nitrogen is via leaching and volatisation. Both leaching and mineralisation are mainly driven by the chemical reactions of nitrification (Formula 1) and denitrification (Formula 2). In the latter process, the so-called ammonification takes an important position. During ammonification, ammonia is freed from organic material, which ultimately becomes subject to nitrification.

Formula 1: Nitrification

$$NH_4- \rightarrow NH_2OH \rightarrow N_2O(\uparrow) \rightarrow NO_2- \rightarrow NO_3-$$

Nitrification is an oxidative process within which ammonia is transferred to nitrite (NO_2-) and further to nitrate (NO_3-), the form of nitrogen which is taken up by plants. The oxidation is by autotrophic bacteria. Like all living organisms, these bacteria react sensitively to their environment, thus creating a link between nitrification and the living conditions of the bacteria. These living conditions are dominated by the water and oxygen saturation of soils and its temperature. The optimal nitrification is at 60% water saturation, 30 to 35°C, and with the high carbon availability needed for bacterial growth (BEESE, 1994 and WERNER, 2004).

Formula 2: Denitrification

$$NO_3- \rightarrow NO_2- \rightarrow NO \rightarrow N_2O(\uparrow) \rightarrow N_2(\uparrow)$$

Denitrification leads to emissions of elemental nitrogen and nitrous oxide. Denitrification takes place exclusively under totally anaerobic conditions. Further, it depends on the presence of anaerobic bacteria, the availability of organic material, and nitrogen oxides. In consequence, denitrification is strongest in weakly aerated soils (highly compacted soils) with high water saturation (humid or flooded soils).

Plant available nitrate is subject to leaching to the groundwater and to surface run-off. During fertilisation ammonium is lost. Denitrified nitrogen is volatised to the atmosphere in form of elemental nitrogen and nitrous oxide. Anthropogenic soil emissions of nitrous oxide are split by the IPCC into “direct soil emissions” and “indirect soil emissions”. The first are linked to nitrogen fertilisation, the second to volatisation, leaching, and runoff. This split is maintained within the current study.

In fertilization, measures that aim to limit emissions of nitrous oxide vary the relation of fast and slow nitrogen according to the demand of crops. In manure management, measures are concerned with storage systems or animal feeding and follow the goal of reducing the nitrogen content of manure. Nitrogen reduced animal feeding is already very common in swine production, with the complementary argument that nitrogen rich feeds are expensive. Storage systems are difficult to control due to the multitude of factors influencing the development of nitrous oxide. Among them are storage compactness (oxygen content), outside temperature, and the duration of storage (WAGNER-RIDDLE, 2001).

2.1.2 Agriculture and Methane

In the year 2000, 49% of all methane emissions in the EU-15 were of agricultural origin (DUCHATEAU and VIDAL, 2003). The main source is enteric fermentation, responsible for 78% of methane emissions. Another 20% is contributed by manure management while the remaining 2% is contributed by rice paddies, agricultural soils, and the burning of residues. In other world regions the contributions of these sources is quite different. In Asia, for example, methane emissions of wetland rice paddies are significant.

The process holding responsible for methane emissions is mostly the anaerobic decomposition of organic material. In this biological process, polymer organic compounds are broken down in four successive steps: (1) hydrolysis: polymer organic material is split into simpler monomers, (2) acidogenesis: micro-molecular decay products are fermented to alcohols and fatty acids, (3) acetogenesis: fatty acids are converted to acetic acid, hydrogen, and carbon dioxide, and (4) methanogenesis: obligatory anaerobic microbes perform methanogenesis, converting acetates to methane and carbon dioxide. Each process is performed by different bacteria, while the last three are by anaerobic bacteria.

The major source "enteric fermentation" is attributable to ruminants. Enteric fermentation allows ruminants digest plants that are rich in cellulose. The main driver for the formation of methane during enteric fermentation is a ration's fibre content (GIBBS and LENG, 1993). Non-ruminant animals, mono-gastric animals, cannot digest cellulose since they lack the relevant bacteria in the digestive tract and their methane emissions from digestion are very small.

Similar conditions to those relevant within the stomachs of ruminants (i.e. anaerobic conditions, anaerobic bacteria, warm temperature, and the presence of organic material) are responsible for the formation of methane in manure systems. Further, pH and C/N-ratio are decisive factors (GALLMANN, 2003). The optimum conditions for methanogenesis are temperatures of 30° to 40°C and neutral pH (GALLMANN, 2003). These factors are also decisive for biogas generation in biogas plant.

In soils, methane forms in wet and organic soils like peat soils featuring anaerobic conditions. On the opposite, soils can also act as methane sink if clearly aerobic conditions prevail. In this case, methane from lower and less aerated soil layers is oxidised in aerobic layers to water and carbon dioxide.

2.1.3 Agriculture and Carbon Dioxide

In relation to global carbon dioxide emissions, agricultural carbon dioxide emissions are negligible. In the EU-15, agriculture contributes only around 0.05% (excluding the emissions from the consumption of energy) respective 1.3% (including emissions from consumption of energy) to carbon dioxide emissions) (VIDAL, 2001). Despite the minor importance of agricultural carbon dioxide emissions, agriculture takes a position of outstanding significance. This is because agricultural production influences the natural carbon cycle by growing crops and cultivating soils. Above-ground biomass in crops takes carbon dioxide from the atmosphere during photosynthesis. Since the equal amounts of carbon dioxide are released during the consumption of the crop (simplified) this is not accounted for in Kyoto emission inventories (in contrast to forest biomass or perennials). Crops used for the production of bio-energy, in turn, often replace fossil fuels thus sparing the release of carbon from the combustion of fossil fuels. If plant material is stored in below ground, the contained organic matter contributes to below ground carbon pools and can be permanent.

2.1.4 Agriculture and Ammonia

Together with sulphur dioxide and nitrogen oxides, ammonia is an important contributor to the acidification and eutrophication of ecosystems. Indirectly it is also a climate relevant gas since eutrophication in the form of nitrogen input ultimately entails nitrous oxide emissions (ASMAN, 2001). The main source of ammonia emissions in Europe is agriculture contributing around 85%.

In agriculture, the main sources are manure management, livestock keeping, and fertiliser application. According to IPCC (1997a), manure management is one of the most important sources of NH_3 worldwide. In livestock keeping ammonia emissions depend on the type of housing especially with respect to exposure of excreta to wind and ambient temperatures. In fertiliser application, the nitrogen content of the fertiliser and the type of fertiliser are the most important factors. Due to ammonification ammonia is released from nitrogen containing substances. It is an enzymatic reaction converting urea (mammals) or uric acid (poultry) to ammonia and carbon dioxide. Ammonia is released until the solution equilibrium between gaseous and dissolved ammonia is achieved. The chemical reactions of ammonification and the ammonia solubility equilibrium are shown in Formula 3. The latter relation shifts towards dissolved ammonium with increasing pH-values and temperatures. Ammonification is mainly after the application of urea fertilisers.

Formula 3: Urea Ammonification and Ammonia Solubility Equilibrium

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2 \rightarrow NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

2.2 Agreements on Climate Protection

With the ratification by more than 55 countries and a representation of more than 55% of the world's CO_2-emissions on the basis of 1990, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) entered into force on February 16, 2005[3]. The Kyoto Protocol is a self-commitment of its signing parties, stipulating a cap on greenhouse gas emissions of industrialised countries. The considered greenhouse gases are six in number and include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro-fluorocarbons (HCFs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

In 1988 the WMO (World Meteorological Organization) and the UNEP (United Nations Environment Programme) established the IPCC (Intergovernmental Panel on Climate Change) as control body and provider of guidelines alongside the UNFCCC. "Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation." (IPCC, 2006a, About IPCC, Mandate)

In the light of an intensified occurrence of extreme climate events during the seventies and rising public awareness of threats to the environment, the first world climate conference was launched in February 1979 in Geneva, initialising a process that culminated in the establishment of the UNFCCC in 1990 and in the formulation of binding CO_2 reduction targets in the Kyoto Protocol. The so-called Annex I-

---

[3] The Status of Ratification can be checked at URL: http://unfccc.int/essential_background/kyoto_protocol/items/12830.php (September, 2006)

countries to the Kyoto Protocol, meaning the signatory industrialised countries, obliged themselves to reduce greenhouse gas emissions by at least 5% with respect to 1990 levels in a first commitment phase from 2008 to 2012.

The EU-15, like many other Central and East European states, agreed to more than comply with this cap and cut emissions by 8%. Within the EU-15, national commitments range from a cut of 28% for Luxemburg and 21% for Denmark and Germany to an increase in emissions of 25% for Greece and 27% for Portugal (UNFCCC, 2008a, Kyoto Protocol, Background). The redistribution of individual targets is regulated in the so-called “Burden Sharing Agreement”, and roughly orientates at per capita emissions (Kyoto Protocol, 2005a).

To aid compliance with their emission targets, the Kyoto Protocol endows Annex I-countries (industrialised countries) with innovative, flexible market based mechanisms aimed at keeping the costs of emission reduction low. Three flexible mechanisms provide cost efficient solutions to Annex I-countries, but also promote the technology and knowledge transfer to developing countries. The first mechanism is an emission trading scheme allowing the trade of so-called “emission certificates[4]” among Annex I-countries with an emission target. The second allows Annex I-countries with an emission target to buy emission certificates from Annex I-countries without an emission target and is called “Joint Implementation (JI)”. The third mechanism, the so-called “Clean Development Mechanisms (CDM)”, allows Annex I-countries to purchase certificates from Non-Annex I-countries. JI and CDM are project based mechanisms, which means that traded emission certificates are generated by climate projects or programs.

In addition to reducing anthropogenic emissions by sources, “Parties may offset their emissions by increasing the amount of greenhouse gases removed from the atmosphere by so-called carbon ‘sinks’ in land use, land-use change and the forestry sector. However, only certain activities in this sector are eligible. These are afforestation, reforestation and deforestation (defined as eligible by the Kyoto

---

[4] Although a number of different emission certificates exists, of which not all of are tradable within the emission trading system, further details will not be discussed here in order to keep it as simple as possible. If interested, please, consult documentation on the following types of certificates (abbreviated): AAU, RMU, ERU, and CER. CERs are generated in addition to other certificates since generated in Non-Annex I countries without proper emission cap. VERs, as further category, do not serve the aim of emission reduction under Kyoto obligations, but form part of the voluntary emission reduction market.

Protocol) and forest management, cropland management, grazing land management and revegetation […].” (KYOTO PROTOCOL, 2005b, Background)[5] Article 3.4 of the Kyoto Protocol grants Annex I-parties free choice as to whether include land-use, land-use change and forestry (LULUCF) as carbon sink into their national emission account for the first commitment period[6].

The Kyoto Protocol imposes upon Annex I-parties reporting responsibilities to the IPCC. A yearly inventory of anthropogenic emissions by sources and removals by sinks of GHGs has to be submitted to the IPCC. A party may decide whether to estimate emissions based on IPCC or alternative methodologies. In any case, it must be done in a transparent and verifiable way.

With respect to the environmental threat of agricultural production a second international agreement on air pollution control is of importance to this study. In the so-called Gothenburg Protocol, emission ceilings[7] for sulphur, NO_x, VOCs (Volatile Organic Compounds) and ammonia were fixed in order to abate acidification, eutrophication and ground-level ozone (UNITED NATIONS, 2004). Of these four pollutants, this study considers ammonia emissions where agriculture contributes a significant share.

2.3 Agriculture as Sink: Capturing Atmospheric Carbon

“The rate of build-up of CO_2 in the atmosphere can be reduced by taking advantage of the fact that carbon can accumulate in vegetation and soils in terrestrial ecosystems. Any process, activity or mechanism which removes a greenhouse gas from the atmosphere is referred to as a ‘sink’." (UNFCCC, 2008b, LULUCF, Background) LULUCF has long been recognised as a cost efficient means for dampening climate warming. Like forestry[8], agriculture also offers a number of carbon sinks. In cropland management, grassland management, or in revegetation

---

[5] Under CDM, an Annex I Party may implement an LULUCF activity in a Non-Annex I country, but is restricted to afforestation and reforestation. Under JI, an Annex I Party may implement projects in another Annex I Party without its own emission target that increase removals by sinks and conform to Article 3, paragraphs 3 and 4, of the Kyoto Protocol.

[6] Upon election, this decision by a Party is fixed for the first commitment period.

[7] The national emission targets can be found at the United Nations Economic Commission for Europe (UNECE, 2006).

[8] This study concentrates on soil carbon sequestration on agricultural lands. Any reader interested in forestry sequestration should refer to the INSEA-network (IIASA, 2007) or likewise to alternative sources.

there are options that can finally lead to (1) soil sequestration of carbon or (2) biomass production on agricultural lands.

The soil sequestration of carbon offers a huge retention respective storage potential since soil contains three times more carbon than vegetation and twice as much as the atmosphere (BOYLE, 2001). Soil carbon sequestration includes schemes that maintain the current land-use but change technologies and managements, and others that imply land-use change. Both schemes potentially affect below- and above-ground carbon stocks by either increasing carbon supply or reducing carbon removal. In terms of land-use change, only the politically motivated abandonment of agricultural production (set-aside) is of interest to this work. The conversion of arable land to grassland, although desirable, is rarely found, due to the competitive disadvantage of grassland products. In contrast, ploughing grassland to arable land faces political opposition[9].

The cultivation of biomass serves the idea of substituting for fossil fuels and thus preventing additional GHG emissions since biomass production and its use is a closed carbon cycle. The entire production chain, from seeding to fuel extraction, thereby decides the economic attractiveness and climate efficiency of the substitute to the replaced product. Biomass ranges from energy crops (plants exclusively grown for energy recovery) to biomass residues (plant by-products of conventional agricultural production). Organic manure from animal production is also a source of biomass residues.

2.3.1 Soil Carbon Sequestration

Soil carbon sequestration could be a major contributor to dampening the anthropogenic greenhouse effect. In this study, carbon sequestration describes a continuous increase of soil carbon stocks at the expense of atmospheric carbon and, in theory, should be of a permanent nature. With a view to climate protection goals, it is the rapid and positive response of soil reservoirs to carbon management that makes soil carbon sequestration a valuable mitigation option. In the light of already troubling climate change time is an important dimension. The IPCC expects a set of harmful effects from climate change to continue for millennia even under stabilized CO_2-concentrations (HOUGHTON et al., 2001).

---

[9] Significant other conversions of e.g. arable land to forests are partially analysed by INSEA project partners.

The functioning of soil carbon sequestration is in such way that atmospheric carbon is bound to agricultural top soils in form of organic matter, e.g. in the humus fraction. The carbon contained in the humus fraction is referred to as humus-C. The relation of humus to carbon is 1.72:1 (BMVEL, 2006). Carbon sequestration is via increasing the input of organic matter to soils and/or by decreasing carbon release. Many agricultural measures address both aspects simultaneously. The most important measures include:

- cultivation of cover crops,
- adaptation of crop rotation,
- soil inclusion of crop residues,
- application of organic manure,
- and conservational tillage.

The term "conservational tillage" refers to the fact that soils are largely "conserved" from disturbance since mouldboard ploughing is decreased or completely avoided. If properly done, limited soil disturbance has the side-effects of improving soil structure, thus widening the soil's water storage capacity, and of controlling erosion. Water household management and soil erosion are important issues on global scale with the latter occurring on 30% of the arable land area worldwide (DAVIDSON, 1999) and with annual soil losses of 0.38 mm (DAWEN et al., 2003). Other positive side-effects of conservational tillage are increased pools of organic nitrogen, improved soil warming, and stabilised pH buffering.

In general, many of the measures mentioned to increase soil carbon sequestration also show positive secondary effects like erosion control or the fixation of nitrogen compounds like nitrates on farrows.

Based on global experiments, WEST and POST (2002)[10] assume yearly carbon sequestration rates between 0.43 and 0.71 t/ha for arable land if soil management is changed from conventional to no-till. On the opposite stand, there are experiments that suggest that conventional tillage with the mouldboard entails at best zero sequestration; carbon freeing may even take place (REICOSKY et al., 1995). The

---

[10] Only soil carbon is considered. The side-effects on other gases are disregarded.

estimate given by West and Post excludes wheat rotations and fallow land. Wheat rotations feature high carbon consumption, if cultivated outside an adequate crop rotation scheme. For continuous wheat RASMUSSEN et al. (1998) assume carbon sequestration at between -0.21 and -0.36 t/ha for the United States of America over a time horizon of 110 - 120 years. So, the sequestration rate cited from West and Post must be excluded for continuous cultivation of wheat.

Besides the restriction of the cited global carbon sequestration rate to certain crop rotations, a further natural barrier is the existence of a saturation level. Lal and associates (LAL et al., 1998) assumed that after 20 to 50 years of continuous sequestration the rates peak off to zero. Also the IPCC restricts the validity of IPCC sequestration factors to 20 years (see for example IPCC, 2006b). The entire process of carbon sequestration is, moreover, reversible. This means once sequestered carbon can be freed from soils to the atmosphere. This occurs, for example, if land use is changed or ploughing is started again on soils previously under a conservational tillage scheme.

So, some aspects that influence carbon sequestration have already been mentioned: soil management, crop history (crop rotation), and natural saturation level. The complex issue of additional determinants shall merely be touched on. The determinants include climate, soil type and soil history. The IPCC suggests the discrimination of mineral from organic soils and of tropical from temperate zones to account for the greatest differences in soil types and climate (IPCC, 2006b, p. 5.17 and p. 5.18), and to consider the level of biomass input (in form of litter or crop residues). As a rule of thumb, clay and loam soils accumulate more carbon than sandy soils.

As has already been mentioned, climate influences soil carbon sequestration rates. In turn, this means that under unrestrained climate change a feedback reaction on soil sequestration will occur. Although feedback reactions from climate change on agricultural production are generally disregarded in this study because of the uncertainty linked to the prediction of such reactions and to their long-term character, the Department for Environment, Food and Rural Affairs (DEFRA, 2002, p. 7) shall be cited. It claims that under unrestrained climate change, global land carbon stocks will release more than 170 Gt of carbon during the next century up to 2100. This is due to soil respiration and die-back of vegetation in South America to an extent that is not compensated by additional vegetation in other world regions. Against this stands a sequestration to the extent of approx. 50 Gt of carbon under a CO_2-level stabilising at 550 ppmv.

Additionally, there is an economic argument which deems mitigation costs for conservational tillage to be competitive with other sectors, and that in some cases even a win-win situation might establish. WANDER and NISSEN (2004, p. 457), for example, monetized the side-effects of increased carbon levels. They perceive positive effects of fertiliser replacement, productivity increment, and improved water quality through better soil structure and soil coverage by plant material.

2.3.2 Biomass to Bio-Energy

Through its pure form or conversion into a solid, liquid and gaseous state, biomass provides multiple forms of energy recovery in stationary plants or in mobile applications. Thereby, biomass is defined as "(…) the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste [and bio-fuels are defined as] liquid or gaseous fuel for transport produced from biomass" (DIRECTIVE 2003/30/EC, Article 2). As mentioned in the beginning, the use of biomass is not exclusively in its original physical condition, but also in dried, liquefied, or gasified. In this study, agricultural biomass in contrast to forest and industrial waste biomass is focussed.

2.3.2.1 Dry Fuels

In agriculture, dry biomass can be a biomass residue or a dedicated crop cultivated for the purpose of subsequent energy recovery. Energy recovery from dry biomass is largely through combustion in stationary plants, mainly in households or in centralised heat and/or power plants. In mobile applications like vehicles, dry biomass is not applied. Typical dry biomass is cereal straw or the energy crop miscanthus (Latin *miscanthus giganteus*). As miscanthus is a perennial crop, it cannot be considered in this study, which describes only independent production cycles of up to one year.

In dry biomass, the controlled combustion of wood and woody material has been undergoing gradual and continuous technological development. Non-woody biomass like straw is not as effectively combusted. This circumstance cannot exclusively be claimed to the longer tradition of wood combustion, but there are also a number of immanent technical problems. Slagging, corrosion, and abundant amounts of ash are among the major shortcomings (MONTGOMERY and LARSEN, 2002). Slagging is because of the comparatively high potash content of straw. Corrosion is due to the high chlorine content, which under high temperatures reacts to alkali salts (e.g. potassium chloride and potassium sulphate). By co-firing straw or other agricultural biomass with wood or fossil fuels at limited shares (around 10% energetic share are state-of-art), these problems can partially be omitted. Also the combustion of “grey straw” (straw left to weathering during some weeks) instead of fresh straw reduces the combustion problems. Co-firing in coal-fired plants is also an interesting alternative, because large incinerators and feed-in technology are already in place and investment costs thus can be kept low. Moreover, coal-fired plants are usually run under a full load, which favours compliance with emission standards, and the relatively low sulphur content of cereal straw leads to favourable overall plant emission values. In contrast, investing in new household power stations or comparable plants for biomass is comparatively expensive (LEIBLE et al., 2007, p.97).

An alternative to the combustion of solid biomass is the so-called “pyrolysis” which has just lately entered discussion. Pyrolysis is the liquefaction in a non-oxidative surrounding. The purpose of liquefaction is the reduction of the remarkable transport costs for bulky biomasses like straw. During pyrolysis, conversion is to oil and coke (called slurry), a liquid mixture which, in straw, for example, reduces density by factor ten. Leible and associates (LEIBLE et al., 2007) analysed a system based on pyrolysis. In this system, the pyrolysis was at decentralised stations, followed by transport of the slurry to centralised stations, where the slurry was gasified in large-scale incinerators. The authors awarded this system higher profitability than centralised combustion solutions for plants above 4,000 MW of gross energy input. So far, only a few experimental plants exist.

2.3.2.2 Liquid Fuels

The main application of liquid biomass is as bio-fuel for the transport sector. Major agricultural raw materials are rapeseed and other oil seeds, or sugar and starch rich plants like sugar beet and wheat. In the production of bio-fuels several conversion processes are applied to the raw material: extraction, esterification, or alcoholic fermentation. Extraction is for plant oils. Extracted plant oils can be used directly in so-called Elsbett-Diesel-engines (Elsbett Technologie GmbH, 2007). Esterification is for plant oils. Esterified plant oil is usually from rapeseed which gives Rape Methyl Ester (RME), commonly referred to as bio-diesel. Alcoholic fermentation is for sugar and starch containing plants. The final product is bio-ethanol. If further refined, bio-ethanol can be converted to ETBE (Ethyl-Tertiary-Butyl-Ether), a valuable petrol additive applied to increase the octane number. In the processes of extraction or alcoholic fermentation apart from the bio-fuel, valuable by-products such as protein rich fodder material (alcoholic fermentation) or fibres accrues (plant oil extraction).

On a global scale, bio-ethanol is the most popular bio-fuel, with consumption of it highest in the United States of America and Brazil. The main raw material is maize (in the USA) and sugar cane (in Brazil). In Europe, bio-diesel made from rapeseed is more popular than bio-ethanol which here is mainly derived from sugar beet and wheat.

With respect to the combustion of bio-fuels in engines, it is allowed in the European Union to blend fuels with bio-fuels in case of ETBE up to 15%, and in case of bio-ethanol and bio-diesel up to 5% (each in volumetric shares) (Roadmap Biokraftstoffe, 2007). These limits are subject to the technical constraints of engines, but shall be increased gradually. Newer engines can run a 10% (E10) blending with bio-ethanol and also for bio-diesel a 10% blending (B10) is envisaged (a combination of 7% bio-diesel and 3% hydrated plant oil). The automotive industry has announced that it will soon release onto the market commercial vehicles that will run on pure bio-diesel (B100), and passenger cars for 85% ethanol (E85) or optionally gasoline, the so-called Flex-Fuel Vehicles (FFV).

The future of bio-fuels is seen in the so-called “second generation fuels” (Roadmap Biokraftstoffe, 2007). Second generation fuels include such developments as the fermentation of higher molecular substances than starch or the carbonisation of carbon rich biomass, or fuel blends above 70% to 90% of bio-ethanol. The fermentation of higher molecular substances will depend on the availability of adequate enzymes and on the enzymes’ production costs. With shrinking costs, however, it may become interesting to ferment straw and other low cost biomass. The carbonisation of carbon rich biomass is for the production of synthetic hydrocarbons or hydrocarbon blends, the so-called BtL process (BtL, Biomass to Liquid). In Germany, one pilot plant for the production of BtL is operating.

One plant is planned for the cracking of cellulose, while commercial use of this will take a minimum of another ten years according to LANGBEHN (2007). She states that BtL features high per hectare yields (4000 l fuel), which outreaches bio-diesel (1400 l) and bio-ethanol (2500 l) by far. High production costs and investment costs stand in opposition to this: they can be 20 times that of bio-diesel plants. In terms of cost reduction, the most promising development would be the application of pyrolysis to prepare the biomass for transport to the BtL-plants.

2.3.2.3 Gaseous Fuels

A further use of agricultural biomass is in its gaseous form. Conversion from the original solid biomass to the so-called “biogas” is in aerobic digesters, where a fermentation process is maintained. The portion of organic substance is thereby subject to fermentation. Fats, proteins, and carbohydrates become methane, carbon dioxide, hydrosulphide (H_2S), and small fractions of other gases (water, nitrogen, hydrogen, and oxygen) (KLINSKI, 2006). The concentration of the combustible methane fluctuates between 50 and 75% (volumetric). Carbon dioxide concentrations are between 25 and 45%, and hydrosulphide concentrations between 0.2 and 0.6 (SCHATTAUER and WEILAND, 2006). Methane is used in Combined Heat and Power (CHP)-units, directly in on-site gas boilers, or feed-in to natural gas grids. In warmer countries the CHP unit is also designed as a cooling and power unit (SCHOLWIN et al., 2006, p. 113).

In terms of fermentation, wet and dry fermentation can be distinguished depending on the dry matter content of the treated mixture. Wet fermentation featuring dry matter contents below 16% is more popular because the substrate remains pumpable, hence facilitating automation (JÄKEL et al., 2000). In dry fermentation dry matter contents between 20% and 40% are common.

Since fermentation is a bacterial decomposition process, optimal living conditions for bacteria need to be guaranteed. Since a variety of bacteria are involved, there is not a unique optimum environment, but at the four steps of methane development (compare section 2.1.2) different living conditions are most favourable to the bacteria (SCHATTAUER and WEILAND, 2006, p.26). The methane generating bacteria are the most vulnerable to external shocks and reproduce relatively slowly, so that conditions are orientated by their requirements. Single-stage biogas plants proceed in this way, while in two-stage plants hydrolysis and acidogenesis are spatially separated and optimised for the correspondent class of bacteria. In the main fermenter either mesophile (32°C - 42°C) or thermophile temperatures (42°C - 55°C) are established. In agricultural plants, mesophile temperatures are preferred since the main types of methane bacteria develop perfectly in this environment and heating costs are limited. Thermophile systems are more sensitive to temperature shocks during substrate feeding, but can serve for the hygienisation of infectious material (like slaughterhouse waste).

The methane yield depends not only on the organic matter availability of substrates, but also on the composition of the same. Contents of digestible proteins, fats and carbohydrates are important sizes (SCHATTAUER and WEILAND, 2006, p. 30). High shares of digestible fat are extraordinarily beneficial for the development of methane, but well-balanced mixtures of nutrients are required since the bacteria involved do not receive all necessary nourishment from a single nutrient. In general, a wide range of biomass substrates can be utilised, ranging from cereal crops or grass to slaughterhouse waste. However, since there are no costs linked to its provision and availability, slurry is the most popular substrate in German biogas plants, where its mass share exceeds 50% (NIEBAUM and DÖHLER, 2006, p. 119). The most popular co-substrate is silage maize.

The basic design elements of a biogas plant are fermenters, gas stores, technical equipment like feeder technology, pumps, and mixers and optionally also CHP units. The CHP unit itself includes a generator and a power machine that is run on generated biogas. Power machines can be either pilot injection or Gas-Otto engines. In pilot injection engines, ignition oil continuously initiates the firing of the biogas, while Gas-Otto engines work according to Otto-technology, without co-fired oil for ignition. Electrical efficiencies of approx. 34 - 40% and thermal efficiencies of 40 - 60% can be achieved (KRIEGL et al., 2005; KTBL, 2006). In central European climates, the fermentation process itself requires 20 - 45% of accruing thermal energy (guide value under Central European climatic conditions). The technical equipment requires around 4% of the accruing electric energy (SCHOLWIN et al., 2006) with a range from 0.5% to 14.0% in plants surveyed in Germany (FNR, 2005, p.113).

From an economic point of view, the utilisation of thermal energy in addition to generated electricity from CHPs is often the main driver that decides upon profitability. This argumentation pleads for the supply of biogas to natural gas pipelines in case waste heat from CHPs cannot be utilized locally. Through so doing, the gross energy of the biogas can be recovered by up to 87.0%, including losses for purification (5%) and for process energy (8%) (PÖLZL and SALCHENEGGER, 2005). So far, the improvement of the gas quality and bringing the pressure of the gas level with the pressure in the gas pipelines are the main obstacles. European gas suppliers or gas network operators demand different gas quality parameters. In feeding biogas into high quality gas networks (H-gas), methane contents between 87% and 99% are requested, while in low quality networks (L-gas), which are less widespread, 80 - 87% suffice (UTESCH, 2007). Technical obstacles include desulphurisation, methane enrichment, gas drying, gas compaction, and gas storage during phases of adverse gas supply and demand (KLINSKI, 2006; KRIEGL, 2005). Advice on appropriate and feasible technology is given by KLINSKI (2002). With respect to profitability of gas feed-in to natural gas grids, economies of scale are large. A threshold is indicated at plant sizes of above 1.0 MW of electric performance (UTESCH, 2007).

2.3.2.4 Additional Specification

Because of the different yields of the grown energy crops, but also because of the different energy conversions into dry, liquid, and gaseous fuels, the achieved energy yields per hectare of land are quite different. This is illustrated in Table 2. The energy yields naturally have to be interpreted taking into account the corresponding crop yields. Further, the demand of crops with respect to climate, soil quality, and fertilization are quite different for energy crops like maize on one hand and rapeseed on the other hand.

When discussing about biomass it should be taken into account that biomass is not automatically a renewable fuel. The control body of the project based flexible mechanism of the Kyoto Protocol, the Executive Board of the Clean Development Mechanism (see section 2.2), fixes the term “renewable biomass” to the conditions that the land-use remains unchanged (e.g. grassland remains grassland), that a sustainable production scheme is in place, and that carbon stocks do not systematically decreased (UNFCCC, 2009).

Table 2: Yield Coefficients of Agricultural Biomass

Crop Input		**Product Output**		**Energy Content**		**Country**
Crop	**Yield**	**Product**	**Quantity**	**Energy**		**(Source)**
	(dt/ha)		(l/ha)	(kWh/ha)	(kWh/dt)	
Wheat	60.4	ethanol	2,170	12,760	211	AT (1)
	70.0		2,500	15,000	214	DE (2)
sugar beet	648.7	ethanol	6,500	38,170	59	AT (1)
	600.0		6,000	36,000	60	DE (2)
rapeseed	35.0	plant oil	1,365	10,500	300	DE (3)
	34.3	diesel	1,523	13,770	401	AT (1)
	(dt/ha)		(m^3/ha)	(kWh/ha)	(kWh/dt)	
Maize	446.2	methane	4,030	38,340	86	AT (1)
	470.0		4,870	49,670	106	DE (4)

Source: (1) Kriegl et al. (2005), (2) Doehler (2006), (3) Schöpe and Britschkat (2002), and (4) own estimate based on Doehler (2006)

2.3.3 Emission Reduction by Bio-Energy

From a climate perspective, the type of biomass and the type of use is of significance. In this study, however, the sole use of interest is energy recovery. Energy recovery itself behaves, roughly speaking, neutrally to climate, since only carbon dioxide that formerly was bound by photosynthesis is freed. The cultivation of biomass, however, may entail GHG emissions due to the consumption of inputs (fuels for tractors or fertilisers). In this context, biomass residues can be distinguished from ordinary biomass. Biomass residues include residues, by-products, and waste streams of agriculture or related industries. Since biomass residues would accrue anyway, GHG emissions due to inputs cannot be attributed to their cultivation. Moreover, the preparation of biomass for energy recovery can entail GHG emissions, in any type of biomass.

The utilization of bio-energy reduces GHG emissions in the quantity of avoided emissions from the utilization of fossil energy displaced minus the emissions for the provision (production, preparation, transport) of the bio-energy resource, if larger than for the provision of the fossil energy resource. The by-products from the cultivation or preparation of bio-energy resources, if used, can displace energy intensive production of the material substituted and thereby additionally contribute to emission reduction. The substitute function of the by-product and the substitute is thereby not always one-by-one. Therefore a conversion factor is drawn based on the main determinant of the replaced product. In case fuels are replaced, the common reference is the calorific value. In the case other materials like fodder the common reference is the main ingredient like protein. The conversion factor would compare the protein contents of the replaced fodder and the by-product.

In the production of biodiesel, in our case RME from non-food rapeseed (the most popular crop for this purpose in Europe), rapeseed wholemeal remains as a by-product from pressing the rapeseed to plant oil, and glycerine remains from the esterification of raw plant oil to RME. The glycerine is a perfect substitute to synthetically produced glycerine. Rapeseed wholemeal is a substitute in animal feeding for the commonly used soy bean wholemeal. Also in the conversion of crops (like wheat or maize) to bio-ethanol, only the sugar respective starch portions are exploited during the fermentative process. The remaining portions together with water and yeast added for the fermentation are dried and further processed into animal fodder. The produced animal fodder, the so-called DDGS (Distillers Dried Grain with Solubles), is rich in proteins and serves to replace soy bean wholemeal.

Table 3: Emission Reduction with Bio-Fuels (excl. Agricultural Emissions)

Substitute		**Original**		**Emission**		
Product	**Share**	**Product**	**Effective-ness**	**Original**	**Sub-stitute**	**Reduc-tion**
(Name)	(t/t crop)	(Name)	(fraction)		(t CO_2e/t)	
Bio-Diesel from Non-Food Rapeseed						
bio-diesel	0.347	fossil diesel	1:1.15	3.598	0.840	**-2.632**
rape meal	0.591	soy meal	1:1.32	0.507	0.285	**-0.131**
glycerine	0.034	glycerine	1:1.00	8.984	0.355	**-8.629**
Bio-Ethanol from Winter Wheat						
bio-ethanol	0.303	gasoline	1:1.62	3.898	0.826*	**-2.560**
DDGS	0.307	soy cake	1:1.48	0.507	---	**-0.343**

**proportionate from bio-ethanol and DDGS production*
Source: own calculations based on: "Effectivity" of substitute and "Share" of bio-fuel product and by-products from UFOP (2001) and Henniges (2006), "Emissions" from Kaltschmitt and Reinhardt (1997)

Table 3 shows the overall emission reduction through renewable bio-fuels unifying the effect from the substitution of a fossil fuel and the substitution of other materials with the by-products of the bio-fuel production. The table is for biodiesel and bio-ethanol. Emissions due to the consumption of agricultural inputs in the cultivation are not accounted for, but only emissions due the conversion process. In this qualified sense, the overall emission reduction (including by-products) would be 1.284 tCO_2e per ton of non-food rapeseed and 0.932 tCO_2e per ton of winter wheat. From the table this calculates as the sum of the products over the quantities of substitute materials (e.g. bio-diesel or rape meal) multiplied by the overall emission. The latter is indicated in tCO_2e per ton of bio-fuel or by-product.

The calculation of emission reductions from biomass energy conversions other than liquid (dry and gaseous) will not be shown, here. This is because a number of products can be substituted and the attribution of a biomass substitute to an original product is thus not that clear. Dry and gaseous fuels potentially replace either thermal or electrical energy. The technologies applied for energy recovery are however large in number and so are the conversion efficiencies. Further, since heat and electricity can be gained in combined heat and power plants, the question whether only one type or more types of energy are replaced raises. How to account correctly for mixed generation? For the focus of this study, which is the agricultural sector, it can be assumed that thermal energy would be generated by captive heat-only boilers since on-site electricity generation in combined heat and power plants that are run on fossil fuels does not make sense for farms. This is because of the seasonal in contrast to constant demand and the relatively low costs of purchased electricity. It is assumed renewable electricity generated from biomass replaces grid electricity as captive electricity generation is rare on farms.

Thus, in terms of emission reduction calculation, the emission factor of light heating oil, as common fuel for decentralised heat generation, given by the IPCC is assumed for captive heat generation. The factor is 3.079 tCO_2e/t of heating oil. For grid electricity, official grid emission factors according to the calculation procedures defined by the IPCC and UNFCCC regulations are assumed. These grid emission factors account for the mix of primary energy at different intervals of the day (e.g. hourly), other factors like the trend of fuel mix in new plants, and it is specific to different dispatch zones and/or national borders.

2.3.4 Bio-Energy Production in the EU

It is the declared goal of the EU-15 to double the share of the Renewable Energy Sources (RES) in total energy consumption from 6% in 2001 to 12% by 2010 and to 20% by 2020 (Directive 2001/77/EC). Bio-fuels for transport shall replace petrol and diesel in the extent of 5.75% (energy equivalents) by 2010 and 10% by 2020 (Directive 2003/30/EC) (EUROPEAN COMMISSION, 2007d). In 2006, however, less than 2% of fuels for transport had been replaced by bio-fuels.

The mix of sources contributing to renewable energy generation in the EU-15 as of 2002 is shown in Table 4. Striking structural differences between the EU-member states prevail. Biogas as renewable energy source was still of minor importance. Only in Belgium it did achieve a share above 10%. In the majority of countries, geothermal and hydropower is dominant. In Austria, France and Sweden, more than 90% of renewable energy is from this source. 'Wind/ PV' (wind and photovoltaic) is dominated by wind power while photovoltaic has only been gradually on the rise from 2002 up to now. The development of photovoltaic is new and is leaded by the Netherlands where the share of photovoltaic is worth mentioning (0.5% total renewable energy share). The cited values do only express the relative importance of different renewable energy sources and they do not state the importance in overall energy generation/ consumption.

Table 4: Mix of Renewable Energy Generation in the EU-15 by 2002

Country	**Biogas**	**Solid Biomass**	**Bio-Waste**	**Geothermal/ Hydropower**	**Wind/ PV**
			(Share in %)		
Austria	0.5	4.2	0.1	94.7	0.5
Belgium	12.1	16.3	35.7	31.0	4.8
Denmark	3.3	12.4	14.5	0.5	69.3
Finland	0.1	47.0	0.5	52.0	0.3
France	0.6	2.2	2.6	94.1	0.4
Germany	6.2	1.5	4.3	51.0	37.0
Greece	2.4	0.0	0.0	81.4	16.2
Ireland	6.1	0.0	0.0	68.9	24.9
Italy	1.3	0.8	1.4	92.4	3.0
Luxembourg	6.3	0.0	15.2	61.4	17.1
Netherlands	8.5	35.1	27.1	3.5	25.9
Portugal	0.0	11.6	5.0	79.9	3.5
Spain	1.4	10.0	2.2	54.1	32.3
Sweden	0.0	5.3	0.3	93.5	0.8

Source: own calculations based on EUROPEAN COMMISSION *(2004)*

Similar to the above described mix of renewable energy sources, the share of renewable energy in total consumption also varies widely from one member state to another (see Table 5). With respect to total gross energy consumption, the share is from 1.0% in Luxemburg to 41.4% in Sweden. For the share of renewable sources in total electricity consumption, binding targets for 2020 have been agreed by the EU. For example, for Austria the target is 78.1% while for Luxembourg it is 5.7%, but both countries started from very different initial renewable electricity shares.

Table 5: Renewable Energy Share as of Gross Consumption in the EU-15 by 2006

	Energy	Electricity			Energy	Electricity	
CP*	Current	Current	Target	CP*	Current	Current	Target
	(Share in %)				(Share in %)		
AT	25.2	56.6	78.1	IE	3.0	8.5	13.2
BE	2.6	3.9	6.0	IT	6.3	14.5	25.0
DK	17.1	25.9	29.0	LU	1.0	3.4	5.7
FI	28.9	24.0	31.5	NL	2.7	7.9	9.0
FR	10.4	12.5	21.0	PT	21.5	29.4	39.0
DE	7.8	12.0	12.5	ES	8.7	17.7	29.4
EL	7.2	12.1	20.1	SE	41.4	48.2	60.0

**CP-Country Plate: AT: Austria, BE: Belgium, DK: Denmark, FI: Finland, FR: France, DE: Germany, EL: Greece, IE: Ireland, IT: Italy, LU: Luxembourg, NL: Netherlands, PT: Portugal, ES: Spain, SE: Sweden*

Source: DG ENERGY AND TRANSPORT (2009).

From the renewable energy sources exploited, solid biomass and biogas are of interest to this study since they represent agricultural sources, although solid biomass is dominated by wood waste and woody by-products. Total solid biomass production for energy recovery in the EU-15 was 54 Mtoe in 2001 and 69 Mtoe in 2003 (EUROPEAN COMMISSION, 2005). The 2010 target of the EU has been set to 149 Mtoe, of which it is estimated that 55 Mtoe will be electricity, 75 Mtoe heat, and 19 Mtoe bio-fuels and switching the fuels for the generation of the same 149 Mtoe from fossil fuels to solid biomass would reduce emissions by 209 million tCO_2e (EUROPEAN COMMISSION, 2005).

Table 6: Heat Production from Renewable Sources in the EU-15 by 2002

Country	Biomass	Solar	Geo	Country	Biomass	Solar	Geo
		(in ktoe)				(in ktoe)	
Austria	2,373.0	74.3	80.0	Ireland	145.0	0.1	1.3
Belgium	384.0	1.0	6.0	Italy	5,613.0	17.1	213.0
Denmark	891.0	9.9	15.7	Luxembourg	24.6	0.1	0.0
Finland	4,818.0	0.8	45.9	Netherlands	324.0	11.3	7.9
France	9,567.0	37.0	196.0	Portugal	1,885.0	19.0	90.0
Germany	5,480.0	158.0	65.2	Spain	3,383.0	35.0	8.0
Greece	962.0	146.0	11.9	Sweden	4,995.0	5.0	299.0

Source: EUROPEAN COMMISSION *(2004)*

Especially in renewable heat production solid biomass has a significant share. This role of solid biomass is not new, but has already existed in the past. In Table 6 the national heat generation from the renewable resources biomass, solar heat, and geothermal heat is listed for the EU-15. It can be seen that in the generation of renewable heat, biomass it the most important resource.

With respect to bio-fuel production in the EU-27, which was mainly for bio-diesel during the agricultural production year 2007/2008, 9.2 Mill t of oil seeds were utilized standing against a total production of 24.0 Mill t and a total consumption of 48.7 Mill t and the production of bio-ethanol required 2.0 Mill t of cereals, equal to less than 1% of total production and consumption, and around 0.8 Mill t of sugar beet in the same production year (EUROPEAN COMMISSION, 2009).

In the EU, bio-energy production is supported by different systems in the member states. Political measures that go beyond enacting minimum standards for renewable energies include tax exemptions (e.g. the European bio-fuels directive (EUROPEAN COMMISSION, 2005)), price subsidies, production quotas, and investment loans at advantageous conditions. In the renewable electricity sector, systems that set a guaranteed minimum price for renewable energies to the grid have been enacted in Germany with the Renewable Energy Act (German: Erneuerbare Energien Gesetz, abbreviated EEG) and in Spain with the Real Decreto 661/2007. The first guarantees prices in biomass for 20 years, the second for 15 years and more. Other EU member states without guaranteed electricity feed-in prices have opted for a quota system. Producers in these states are exposed to normal price risk, reflecting finally in higher prices with simultaneously low production security (FNR, 2006).

Despite these incentives, renewable energies often face difficult economic conditions, since fossil fuels are usually more competitive and/or their logistical systems better developed. In 2005, for example, even the worldwide cheapest bio-ethanol could be imported at 680 €/toe while petrol was traded at 457 €/toe (equal to 60 €/barrel at the exchange rate of 1.25 $:1.00 €) (EUROPEAN COMMISSION, 2005). European bio-energy products are often not competitive with world market prices for the same products, but European producers are sometimes protected by barriers like the European biodiesel standards for unadapted vehicles (FAME, EN 142114).

3 Methodology

This chapter creates the link between the research questions and the methodologies applied to tackle them. Methodologies will be analysed critically and judged according to effectiveness and to alternative methodologies, as appropriate.

3.1 Modelling Context

It would be difficult to overestimate the diversity of agricultural production, agricultural products, and farm structures for the study region, the EU-15. This abundant diversity has its roots in a geographical extension that spans various climatic zones, in a moved development history influenced by traditions and industrialization, and in the political background, all factors which have left a mark on today's EU agriculture.

3.1.1 Natural Conditions in Study Region

Natural conditions for agricultural production are diverse across Europe. A number of climes (see for example LAUER and BENDIX, 1995) and also topographical zones cultivated by agriculture can be found. The European climate is widely influenced by the Atlantic Ocean with the Gulf Stream. In the Western parts, relatively flat regions permit Atlantic wind to enter into continental zones. Even in Norway, or especially in Norway, the influence of the Atlantic can be clearly noticed. There, even north of the Arctic Circle, the Gulf Stream maintains the coastline ice free during most of the year. In contrast, Eastern Europe or the European part of Russia is dominated by a continental climate. A continental climate features more extreme weather, especially temperature conditions. As regards precipitation, the influence of the Atlantic is also noticeable. At the Norwegian coastline bordering the North Sea, high rainfalls of up to 2000 mm/year are registered, while east of high ranges breaking wind from the coastal zones (i.e. in continental zones) a precipitation level of around 500 mm/year is typical (ÖSTERREICHISCHE HAGELVERSICHERUNG, 2007).

In summarizing these peculiarities of agricultural production in the EU-15 and adding some structure influencing factors, Table 7 was produced. It shows the EU-15's extreme values for climate and for farm structural indicators and simultaneously names the country respective region of occurrence.

Table 7: Agricultural Production Conditions and Structures in the EU-15

Item		Minimum Value	Minimum Region	Maximum Value	Maximum Region	Mean[11] (EU-15)
temperature	(°C)	-2.0	Övre Norrland	16.6	Notio Aigaio	8.7
precipitation	(mm/a)	486.8	Murcía	1,687.6	Valle d'Aosta	876.4
milk yield	(quintal/cow/a)	47.3	Greece	79.9	Sweden	60.8
herd size	(cows/keeper)	8.0	Greece	64.0	Denmark	29.0
UAA	(ha/farm)	4.4	Greece	45.8	Denmark	18.8
cereal area	(ha/farm)	3.1	Portugal	28.3	Denmark	13.9
wheat yield	(dt/ha)	90.5	Ireland	10.2	Portugal	64.1

Source: own calculations based on FUCHS *(2005) average data for several years; and based on ZMP (2004a), and ZMP (2004b) data for 2001.*

Although Europe is highly industrialised, it maintained a diverse and well-developed agricultural production sector. Generally, it could be assumed industrialisation slowed down agricultural development, due to increased competition for land. However, through industrialization the market for agricultural products, especially processed products, diversifies and increases (although not proportionally to other sectors).

With respect to the land use, it can be shortly summarised that almost all land in Europe is rainfed. The largest share is arable land followed by coniferous land and grassland as can be seen in Table 8.

Table 8: Land Cover on the European Continent (Agriculture and Forestry)

Land Category	Area	Land Category	Area
	(1,000 ha)		(1,000 ha)
coniferous forest	281,927	permanent crops	11,696
grassland	127,978	shrub and barren land	64,867
rainfed arable land	309,130	permanent ice and snow	8,783
irrigated arable land	7,067	wetlands	34,205

Source: PELCOM (2006)

3.1.2 Political Conditions in Study Region

Under the political areas transferred by its member states to the European Union's common policy, the second largest area with respect to the overall budget is "Natural Resources". Besides rural development, environment, and fishery, this area includes

---

[11] The mean is not weighted (e.g. according to surface), but merely represents the average over all NUTS-II regions for the EU-15.

agriculture, the area to which until 2013 43.0% of the EU's budget will be targeted (EUROPEAN COMMISSION, 2007c). This stresses agriculture's significance for EU-policies, but also testifies to large-scale intervention in agricultural production. In this study, this importance is partially reflected in extensive discourse on this topic examined in the following section.

3.1.2.1 1992 Agricultural Policy Reforms

Against the background of imbalanced agricultural markets, rising pressure from international trade negotiations to lower agricultural subsidies (agreement launched in 1986 by the GATT Uruguay Round) and non-competitive parity of agricultural incomes, in 1992 the European Union saw itself compelled to reform agricultural policies that so far had been based on price support. Under the "1992 Common Agricultural Policy reforms[12]" price support cuts, widening the use of compensatory payments, and direct supply management were agreed upon (Regulations (EC) Nº 1765/1992 and Nº 1766/1992). Social aspects were observed by the partial modulation of payments according to farm sizes, thereby addressing the situation that only 20% of farmers received more than 80% of total support.

The reduction resulting from the abolition of institutional prices was compensated for by means of crop-specific hectare payments in the so-called COP- (Cereals, Oilseeds, and Protein crops) sector (EUROPEAN COMMISSION, 1997). An institutional storage system steered by the mechanism of institutional prices was the main instrument to regulate the internal agriculture market, at the same time guaranteeing a certain minimum price level to producers. For cereals, the reduction of institutional prices was, on average, by one third of the 1992 level, implemented gradually in three steps from 1993 to 1996. External trade regulations were modified in the light of rising international pressure applied by the Uruguay Round Agreement. Negotiations led to lower border protections and to fixing duty-paid import prices (threshold prices) so that they would not exceed 155% of the effective institutional price, while for oilseeds and protein crops institutional prices were completely abolished[13].

For the maintenance of a certain level of income parity with other sectors, farmers could benefit from compensatory payments. Receipts were orientated by the "Historic

---

[12] Since its introduction in 1960 the Common Agricultural Policy (CAP) represents an area of shared competence between the EU and its Member States and as such is binding to all Member States.

[13] Border protection for oilseeds and protein crops never existed.

Yields (HY)", representing an average yield from the production years 1986/87 - 1990/91, whereby the two most extreme years were excluded. The support was given only on the condition that farmers set aside a defined percentage of the total land for which aid was requested. By so doing, support has partially been decoupled from production since current yields are irrelevant. However, this procedure kept payments crop-specific.

Upon assessing the 1992 CAP reforms, the EU Commission educed that agricultural incomes had been raised despite the obligatory set-aside regulation. At the same time, the concentration of production had been curbed in the most fertile regions, while maintaining production in less favoured areas. From an environmental point of view, the reduction of crop prices made farmers moderate the use of inputs like fertilisers. A detailed analysis of the 1992 CAP reforms can be found in the working document of the Directorate General for Agriculture of the European Commission (EUROPEAN COMMISSION, 1997).

From a modelling point of view, three aspects are of interest. First, the payments were restricted to so-called "eligible land", excluding formerly non-arable land. Second, national ceilings were amended in order to limit total budgetary expenditures. Third, the regulation applying a different scheme for large scale farmers, i.e. farmers whose request exceeds an area corresponding to more than 92 t of historic yield, requires special model set-up[14]. The solutions will be described later.

3.1.2.2 AGENDA 2000

Notwithstanding the achievements of the 1992 reforms, in the light of an enlargement of the European Union and the enhanced need to find a solution to contemporary and future challenges, in 1999 the heads of government agreed on the so-called AGENDA 2000. At the Berlin summit, key policies like regional and agricultural policy were subject to reforms. It was agreed that the first of these, initially introduced to give expression to solidarity among European nations, would be continued, and it still forms one of the main pillars of European policy.

The AGENDA 2000 (Regulation (EC) No 1254/1999) continues most of the 1992 measures. However, from the harvest of 2000 onwards, crop-specific payments were

---

[14] For large scale farmers payments are crop specific and setting aside is mandatory. Small scale farmers in turn can freely decide whether to set aside land, and payments are not crop-specific.

transferred to unspecific ones and farmers were allowed to voluntarily set aside more than the mandatory rate if not exceeding 33% of total eligible area. The production of energy crops was promoted by allowing farmers to use set-aside land to grow non-food and non-feed crops while receiving the set-aside premium. The payments' values are summarised in Table 10, column "Pre-2003".

Intervention in the animal sector was in the form of an incremental price decrease, finally totalling 20%, while at the same time reinforcing market orientation and private storage. Price reductions were compensated for by augmenting and supplementing already existing payment schemes from the pre-AGENDA regulation. The total number of animals qualifying for the existing special premium and the suckler cow premium was limited by a stocking density[15]. In order to qualify for the stocking density the farmer had to designate a so-called "forage area[16]".

The *special premium for male cattle (SPM)*, a one-off payment[17], and the *suckler cow premium (SCC)*, an annual payment, were only granted to eligible cattle, i.e. all cattle minus dairy cows. For the SCC the livestock could be composed of up to 20% heifers.

Producers that received the special premium and/or suckler cow premium qualified for an *extensification premium (EXT)*. The extensification premium rewarded farmers that achieved and maintained a reduced stocking density. The member states could set one of two alternative thresholds: The stocking density[18] is 1) between 1.4 and 1.8 LU/ha, or 2) below 1.4 LU/ha.

The *slaughter premiums for calves (SLC) and adult cattle (SLA)* could be granted to cattle of a certain age and weight class. If the member state opted for a *ewe premium (SHG),* it was per animal without further specification, whereof the sale of ewe milk or milk products had to entail a 20% premium reduction.

Despite the complexity of these animal premium schemes and multiple reference points, the value of the base premiums was predefined and uniform across the EU.

---

[15] The relevant size is the livestock units (cattle between 6 and 24 months old: 0.6 LU, cattle older than 24 months: 1.0 LU, dairy or suckler cows: 1.0 LU, sheep or goats: 0.15 LU).

[16] All permanent grassland and areas subject to mixed cultivation or in shared use could be requested as forage area. Arable land could be declared as forage area if it was not included either in the COP support system or in the special support system (dried fodder support), and if it was not used for any permanent or horticultural crops but as pasture (Article 12, Regulation (EC) No 1254/1999).

[17] A second payment could be requested only for steers if they were older than 22 months.

[18] The determination of forage area for the extensification premium slightly deviates from its determination in the context of cattle premiums.

From 2000 to 2002, the base experienced a gradual increase in order to smooth the transition to the “Reformed AGENDA 2000” (correspondent values can be found in Annex 5). Apart from the base values, special regulations like the *deseasonalisation premium (DSP),* or the granting of the *additional payments (ADD),* where countries are permitted to raise base premiums so long as national limits are not exceeded (Article 14, Regulation (EC) N° 1254/1999), create a situation with a multitude of national premiums reinforced by national implementation choices.

3.1.2.3 Beyond AGENDA 2000: Sugar Production

Although exempted from the support system, it is worth describing production conditions for sugar beet production separately due to its high specific gross margins (sugarcane, because of its minor importance for Europe, is neglected). The common market organisation for sugar regulates European sugar production, protects the domestic market, and promotes exports. A quota system endows production volumes for which prices above world market level are guaranteed. The quota system differs between A-, B-, and C-beets. The A-quota is tailored to satisfy EU respective national consumption, the B-quota is meant to meet the sugar export potential. The C-quota was for exuberant sugar. It had to be marketed at world market conditions. Production limitations exist only for the A- and B-quota[19], while the splitting was 82% against 18% in Europe in 2005 (EUROPÄISCHE KOMMISSION, 2005).

Import tariffs are levied on sugar and by-products from sugar refining in order to protect internal markets, while export subsidies are granted to help market exuberant sugar. Imports from the French DOM (French: Départements d’outre-mer), the ACP (African, Caribbean and Pacific) states (regulated by the Cotonou Agreement), and some LDC (Least Developed Countries) are exempted from the high tariffs.

Table 9: Sugar Beet Institutional Prices in Quota Types

Group	Countries	A-Quota	B-Quota
		(€/t)	
G1	Germany, France, Benelux, Denmark, Greece, Italy, Austria, and Sweden	46.72	28.84
G2	Great Britain, Ireland, Portugal, and Finland	48.62	30.74
G3	Spain	48.92	31.04

Source: BARTENS *and* MOSOLFF *(2002)*

---

[19] As such the C-quota cannot be understood as a quota in the original sense, but since this term has become established, it is also used in this study.

The institutional price for sugar beets (respective of white sugar) is fixed at country (group) level (see Table 9). It composes of the beet standard price, at 16% standard sugar content, and it is changed by 1.0% per 0.1% deviation from the standard sugar content (Regulation (EC) N° 1261/2001). For sugar contents between 16.0 - 18.0%, minimum bonuses of 0.9%; between 18.0 - 19.0%, of 0.7%; and between 19.0 - 20.0%, of 0.5% are awarded. The maximal diminution is 0.9% for sugar contents between 16.0 - 15.5%, and 1.0% between 15.5 - 14.5%.

3.1.2.4 Reformed AGENDA 2000

Already during the conception and formulation of the AGENDA 2000, a midterm evaluation had been stipulated. Findings of the same Midterm Review (MTR), and increasing pressure from the WTO II negotiations that weighed on the European Union, reinforced reformative endeavours which went beyond original agreements. Under the headline of “2003 reforms of the AGENDA 2000” the gradual introduction of a Single Farm Payment (SFP) until 2013 was enacted (Regulation (EC) N° 1782/2003). The amendment entails three main principles: (1) the decoupling of direct payments, (2) the coupling of direct payments to compliance with environmental protection, animal welfare, and food security regulations, and (3) the partial re-allocation of payments to rural development.

With the 2003 reforms, cross-compliance measures i.e. the coupling of payments to compliance with other measures, have become mandatory in all member countries. The mandatory shift of funds from the first pillar (market measures) to the second pillar (rural development) of European agricultural policy, so-called modulation, has ceded to every holding a franchise of 5,000 €. Within this modulation a rate has been set that foresees the reduction of total payments by 3% in 2005, 4% in 2006, and annually 5% from 2007 - 2012. In Table 10 the other main differences of the pre-2003 and post-2003 AGENDA 2000 are listed.

Table 10: AGENDA 2000: Before and after the 2003-Reforms

Item	**Pre-2003**	**Post-2003**
arable land	Payments conditional on setting aside and coupled to production: - set-aside: HY×63.00 €/t - cereals: HY×63.00 €/t - oilseeds HY×141.12 €/t - rice: HY×102.00 €/t - starch potato: HY×110.54 €/t Intervention prices, export subsidies.	Single decoupled farm payment based on historic (from 2000 to 2002) payments for arable land and animal production. Exempted from decoupling: - Starch potato: 60% in DK and FI (equals 66.32 €/t) - Rice: 100% in main European production countries
set-aside	Compulsory: 10% of arable crops on eligible land (small-scale producers exempted) Voluntary: up to a total of 33% of eligible land Payment: HY×63.00 €/t	Compulsory: pre-2003 obligation Voluntary: up to 100% Payment: entitlement based on historic receipts and obligations
protein crops	9.50 €/t	55.57 €/ha
energy crops	allowed on set-aside land Payment: set-aside premium	allowed on set-aside land Payment: 45.00 €/ha (on grassland and arable land but not set-aside)
Rice	Payment: HY×102.00 €/t	France: 411.75 €/ha, Greece: 561.00 €/ha, Italy: 453.00 €/ha, Portugal: 453.75 €/ha, Spain: 476.25 €/ha
Milk	Intervention price Export subsidies Milk quota	Intervention price from 2003-2007 gradually lowered by a total of 25% for butter and by 15% for skimmed milk. Quota: +0.5% in 2006-2008 Milk premium 35.5 €/t; thereafter part of SFP
sugar beet	Intervention price (€/t of beet): G1: 47.67, G2: 49.57, G3: 49.87 Import tariffs, export subsidies	Intervention price (€/t of beet): 2006: 32.86, 2007: 29.78, 2008: 27.83, 2009: 26.29
extensification	100 €/ha for stocking rate below 1.4 LU/ha (>=50% of forage area must be pasture)	100 €/ha for stocking rate <1.4 LU/ha or 40 €/ha for stocking rate from 1.4-1.8 LU/ha or 80 €/ha for rate <1.4 LU/ha

Source: own presentation based on GAY *et al., (2005) and* COUNCIL REGULATION *(2006).*

It was recognised that the disbursement of direct payments had still been dependent on the commitment to set-aside obligations before the amendment of reformed CAP-regulations in 2003, and with the reform this order was abandoned. Subsequently, farmers were provided with an economic basis for their production decisions, instead of politically focussed crops. The pre-2003 set-aside obligation applied to so-called eligible land, and did not include forests or permanent crops grown on arable land (Regulation (EC) N° 1765/1992, Article 9). Since then, sugar beets and potatoes have become part of the eligible land and have satisfied the conditions for receiving premiums.

The strongest impact of the reforms on agricultural incomes was from the derogation of institutional prices and the abolition of export subsidies for a variety of products:

- In rye production, institutional prices have been completely abolished as a reaction to large intervention stocks. Regions where rye production contributes a considerable share of farming income benefit from extra financial backflows gathered by the modulation mechanism. Normally, a minimum share of 80% of backflows of financial means from modulation are granted to the country of origin, but in this special case the minimum share has been augmented to 90%.
- In dairy production, significant price cuts for butter (25%) and skimmed milk (15%) have been pushed (Regulation (EC) N° 1787/2003), simultaneously increasing milk quotas yearly by 0.5% during 2005 to 2007 (in total 1.5%). The milk quota regulation has been prolonged until 2014/15. Further milk price cuts are compensated for via a newly introduced milk premium that after decoupling, as and from 2005 to 2007 depending on the member state (see Table 10), was to gradually merge into a single farm payment.
- As regards the common market organisation for sugar, the European Council agreed in November 2005 (Regulation (EC) N° 318/2006) on its reformation. A reduction of sugar beet institutional prices by 39% was envisaged in conjunction with a 60% compensation for income losses via an acreage payment. The payment in the course of the AGENDA 2000

reforms will merge into the single farm payment. A claim by Australia, Brazil, and Thailand to the WTO against European sugar market protection urged decision takers to reform also the sugar sector, which up until then had been exempted. The three claimants argued exports originating in the European Union (C-sugar) were cross-subsidised via the A- and B-quota system and would thus oppose WTO agreements. The WTO had decided that the EU had to abolish its export subsidies and C-sugar production[20]. The traditional A- and B-quotas were merged in a single quota and countries that so far had administrated C-quotas were permitted to offer additional sugar quotas for sale at a one-off amount of 730 €/t of quota levy.

3.1.2.5 Transition to the SFP, Reformed AGENDA 2000

Although the decoupling of direct payments from production is a main principle of the 2003 reforms of AGENDA 2000, some payments will remain coupled. This is, however, an exemption and only valid during a transitional period and in some countries. The transitional period lasts until 2013, when all member countries must have achieved full decoupling and must have introduced the SFP scheme instead. The SFP generally will include all COP payments plus the starch potato and dried fodder aids. Some cultures of extraordinary regional economic significance like durum wheat, tobacco, hops, or olives will continue to receive coupled payment.

The transition to the SFP is regulated at member state level but has to follow one of the following three choices: the so-called (1) historic model, the (2) regional model, or the (3) hybrid model. In model (1) payments are based on the farmers' historic receipts represented by the holding's average support received between 2000 and 2002 i.e. farmers are rewarded an individual payment. In model (2) regionally specified acreage payments are envisaged based on premiums paid to the population of farmers in the same region. In model (3) a regionally specified acreage premium is supplemented by individual historic farm receipts, the "top-ups". The top-ups are predominantly composed of payments into the animal line of production. Independently from the selected model, a hundred percent of historic payments merge into the SFP. Only in Luxembourg do farmers merely receive 65% of the

---

[20] In 2005 the EU lost the so-called "Sugar Panel" and subsequently faced the prohibition of C-sugar production and the re-export of sugar from ACP countries imported up until then to the EU under preferential conditions (DBV, ADR, and WVZ, 2006).

historic COP premium, and 85% of the historic suckler cow premium. In return, they are compensated with 90 to 95 €/ha of agricultural land.

Among other countries, Denmark and Germany chose the hybrid model (see Table 11). For the two countries, estimated values about the extent of the acreage payment are already available. In Denmark, farmers will, according to the model, be granted 310 €/ha for arable and rotational grassland, and 67 €/ha for permanent grassland by the target year 2013. In Germany the payment will, according to the model, be 328 €/ha and is equal for all (eligible) land (Gay et al., 2005). Since Germany selected the regional option[21], slight regional deviations from those 328 €/ha are system imminent (further details in Stolk et al., 2006).

Table 11: SFP-Transitory Models Selected by the EU-15

Country	SFP-Type	Start of Decoupling of Dairy Payment	Maintained Coupling Rate of Animal Payments[22]				
			SCC	SLA	SLC	SPM	SHG
		(year)			(%)		
Austria	historic	2007	100	40	100	0	0
Flanders	historic	2006	100	0	100	0	0
Wallonia	historic	2006	100	0	0	0	0
Denmark	hybrid	2005	0	0	0	75	50
Finland	hybrid	2006	0	0	0	75	50
France	historic	2006	100	40	100		50
Germany	transitional hybrid	2005	0	0	0	0	0
Greece	historic	2007	0	0	0	0	50
Ireland	historic	2005	0	0	0	0	0
Italy	historic	2006	0	0	0	0	0
Luxembourg	hybrid	2005	0	0	0	0	0
Netherlands[23]	historic	2007	0	100	100	0	0
Portugal	historic	2007	100	40	100	0	50
Spain	historic	2006	100	40	100	0	50
Sweden[24]	hybrid	2005	0	0	0	75	0

Source: Gay et al. (2006), European Commission (2007b)

Apart from the described differences in the national processes the countries select in the transition to the SFP, nationally defined payments and systemic differences in the payment regulations exist for catch crops.

---

[21] This corresponds with the national choices stipulated in Article 58, (EC) No 1782/2003.

[22] For the declaration of abbreviations see the previous section.

[23] Decoupling from 2010 onwards.

[24] Decoupling from 2009 onwards.

3.1.3 Economic-Ecological Models in Agriculture

In the context of simulating GHG emissions and their interaction with corresponding control systems with the economy, a range of economic models has been conceived. The economic part of those models has been developed as programming model optimizing single enterprises or as market models balancing supply and demand. The coexistence of both approaches suggests that each one features specific advantages and disadvantages. These particularities shall be shortly described in the following by giving an assortment of (programming) models that are concerned with the same topic as the current study.

3.1.3.1 FASOM

LEE and MCCARL (2005) ran a market model, a partial equilibrium model, the so-called Forest and Agricultural Sector Optimisation Model (FASOM), to analyse the mitigation potential in the Kyoto relevant LULUCF sector (land use, land use change, and forestry), including land-use change, in the United States of America. Among other issues, the research questions addressed sequestration potential, price development of food and non-food products, and labour market.

The model's objective function maximises the producers' and consumers' surplus and uses a calculation of market equilibrium based on econometrically deduced price elasticities of demand and supply. The maximisation is subject to resource limitations, and policy constraints, but also to a number of ecological parameters. The eligible activities under carbon sequestration Articles 3.3 and 3.4 of the Kyoto Protocol can be analysed for forests, cropland and grassland management.

By its multi-periodic dynamic formulation, FASOM makes it easy to analyse perennial crops and forest growth while including predicted trends of price or yield developments. FASOM, like other market models, features the endogenous simulation of prices by clearing supply and demand (market model). Against this extensive simulation of macro-economic coherences stand the uncertainty of long-term predictions in dynamic programming models, and the aggravated integration of the latest technologies in case time-series data is lacking.

3.1.3.2 CAPRI

The model applied by PÉREZ DOMÍNGUEZ (2006) is a combination of a macro-economic equilibrium module and a micro-economic supply module. He simulated GHG abatement costs for the EU-15's agricultural sector. Designed at the end of the nineties to analyse the impact of the CAP (Common Agricultural Policy) on regional agricultural income, the so-called CAPRI-model (Common Agricultural Policy Regional Impact) has been undergoing various steps of refinement and amplified application until the current day.

CAPRI's core is constituted by a market module and supply module that are iteratively[25] coupled and brought to an equilibrium condition. The supply module simulates regional agricultural supply under the assumption of profit maximising producers. Profit maximisation thereby is achieved by determining the optimal combination of production, optimal intensities, and minimal cost combinations under a set of constraints arising from nutrient requirements, scarcity of production factors, and so forth. Within the market module, world-wide agriculture and agro-industry is broken down into twelve trading zones, each one featuring systems of supply, human consumption, animal feed and processing functions. The parameters of the market module are based on elasticities. Consistency between the supply and the market module, the supply module operating on administrative regions and the market module operating on national or higher scale, is obtained by the aggregation of the supply module's coefficients and the subsequent calibration through PMP (Positive Mathematical Programming) methods. Results of the market module are vice versa scaled down to fit the supply module.

Advantageous to this approach is the consideration of the entire agricultural sector including verification through top-down statistics and endogenous simulation of sales prices. However, policy impacts on the farm level are more difficult to capture than they are by pure linear programming models, due to the PMP assumptions. Farm type specific impacts cannot be analysed.

3.1.3.3 EU-EFEM

The foundation for EU-EFEM was laid down in the late nineties with a model on the impact of regional agricultural and environmental policies (KAZENWADEL, 1999). Within an integrated approach, environmental parameters from precedent studies (KRAYL, 1993) were integrated into an economic framework. The economic framework was provided by an optimisation model of the linear programming type, maximising the total gross margin of farms. The regional scope was on the Southern German state of Baden-Württemberg, where the model was simulated within eight

---

[25] The different ways of coupling are explained in section 3.2.3.

homogeneous regions with respect to natural conditions. By that time the modelling units were “region typical farms” for which all relevant farm activities of the plant and animal lines of production were represented (SCHÄFER et al., 2003).

This original model was enhanced by ANGENENDT (2003) to form the so-called EFEM (Economic Farm Emission Model). She complemented further environmental coefficients, especially emission factors, and made the model ready for the analysis of climate relevant gas emissions. Further refinement was achieved by SCHÄFER (2006) through coupling EFEM with a biophysical model, thereby integrating site-specific emission estimates. Like Kazenwadel, he modelled the Baden-Wurttemberg agricultural sector on the basis of region typical farms for a range of political scenarios.

The EU-EFEM model, a further extension of EFEM, allows for the variety of factors necessary to accurately depict the EU-15’s agricultural diversity to be taken into account. The bottom-up approach features the simulation of region typical farms and the consecutive extrapolation of single farm results to regional results. Through maintaining region typical farms as modelling units, similarity to real farms with respect to the resource endowment is assured. Extrapolation controls the representation of the regional production capacities and at the same time observes farm structure.

EU-EFEM is a Mixed-Integer Programming (MIP) model that maximises the farm gross margin. In contrast to FASOM and CAPRI, EU-EFEM is a pure supply model, i.e. prices are exogenous. The model features high regional resolution, and a deep disaggregation of agricultural production and framework conditions. The bottom-up approach, from farms to regions, allows for an accurate farm level modelling and leaves open the option of dismantling the trade-off between high resolution and regional coverage. By the promotion of data exchange with other model types, via ad hoc established interfaces, some of the disadvantages of micro-economic modelling are surpassed. The data exchange is via linkages that are described in section 3.2.3.

The applied linear programming respective MIP is popular for the planning and optimisation of complex farm level production decisions. A standard linear programming problem for k farms, n production activities and m constraints can be formulated as:

Objective function: **max** $\Phi_k (x_k) = g_k \times x_k$

Subject to: $A_k \times x_k \leq z_k$

$x_k \geq 0$

X_k denotes the *n*-vector of production activities of a farm and g_k the *n*-vector of objective values. A_k defines the matrix of production coefficients for all constraints, whereby z_k determines the *m* capacities. Summarising the single gross margins of production activities, the objective value Φ_k expresses a farm's total gross margin.

An applicability criterion of LP-models is the constancy of input-output-coefficients, a precondition which can be partially relaxed by introducing binary decision variables. MIP, in contrast to linear programming, allows for the integration of binary variables. Binary variables (or decisions) are sometimes necessary to depict agricultural policies on farm-level, for example. A prominent example from agricultural policy is the European set-aside obligation of the AGENDA 2000, which is only mandatory for farms exceeding a certain total cereal production quantity. This jumping relation between cereal production and set-aside obligation can be depicted by the MIP approach. MIP is also a valuable tool for the integration of fixed costs dependent upon the realisation of a certain project or production alternative.

3.1.4 Modelling Software

As mentioned before, the conception of EU-EFEM was influenced by its affiliation to the interdisciplinary and integrated INSEA-project. The installation of synergy effects is expected, since a common data base has been created and a common programming language has been agreed upon. Sharing a common data base and programming language promotes the exchange of data, programming skills, and gives more rapid access into linked models. This section introduces the common programming language. The common data base's structure will be explained later, along with the organisation of the data exchange (see section 3.2.3).

In order to reach an agreement on a common programming language, it was most important to identify the models of likely data exchange. A common programming language only is necessary for these models. Within the framework of the INSEA project, all other models of likely data exchange with each other and with EU-EFEM were written in GAMS (General Algebraic Modelling System), but not EU-EFEM. The predecessor to EU-EFEM, the latest EFEM version, is programmed in Microsoft-Excel. Its worksheet architecture fosters logical structuring. The motivation for switching to GAMS, in contrast, can be summarised as follows:

1. Other INSEA models had already been written in GAMS, so that the common language eased the creation of interfaces and the exchange of programming skills or code.
2. The amplification of the regional scope from EFEM to EU-EFEM would have entailed large logistical efforts including renewal of the majority of data tables in the EFEM Microsoft Excel version.
3. In view of future applications, EU-EFEM's structure and approach will have to cope with higher requirements making the higher flexibility of GAMS (e.g. not restricted to LP solvers) an asset.
4. The GAMS software offers helpful debuggers.
5. Traceability is being improved through the user friendly support of documentation within the GAMS programming code.

3.2 Model Interfaces

Already earlier versions of the economic-ecological EFEM relied on simulation by biophysical models like DNDC[26] (described in SCHÄFER, 2006). Continuing these positive experiences and coping with the requirements from the engagement in the INSEA project, linkage to and exchange with other models has also been sought for EU-EFEM. Hereafter, general ways of linking models as well as the concrete case of linking EU-EFEM to other models of the INSEA network will be shown. In this context, first of all, the structure of INSEA's project database where participating models (partially) satisfied data needs will be explained.

3.2.1 Data Base and Data Structure

In order for the INSEA-project to follow an integrated approach, the central question is how to bundle and satisfy the variety of data needs of participating partners. Data inputs and outputs have to be arranged in such a way that partners can mutually exchange data as good as possible (SCHNEIDER et al., 2004). The data needs of the

---

[26] De-Nitrification De-Composition Model (for example LI et al., 1996)

entire network are extensive and range from economical parameters (costs, profits, etc.) to biophysical data (weather, soil, etc.) to management data (management practices, application dates).

A precondition for the exchange and the common use of data is agreement on a common regional resolution. Participating models are run on NUTS-0 (country), NUTS-II (district), or on a 1 km grid level. Within INSEA the 1 km grid resolution was agreed upon for biophysical models. The NUTS definition of regions was agreed upon for economic models. The market model EU-FASOM is run on a country level (NUTS-0) because trade balances and other economic data are on a country level. The programming models $\text{AROPA}_{\text{GHG}}$ and EU-EFEM are operated on the finer resolution, on NUTS-II. For EU-EFEM, the modelling on NUTS-II level meant a cut with respect to its predecessor EFEM, which relied on a regional delineation according to homogenous natural conditions.

Sales prices, important to the calculation of the EU-EFEM objective value the gross margin of production activities, are not provided by the INSEA database. Because of the high variety of sales prices between databases, prices from several sources were intersected for EU-EFEM, namely from KTBL (KTBL, 2005), ZMP (ZMP, 2005), Statistical Yearbooks (STATISTISCHES JAHRBUCH, 2005), and EUROSTAT (EUROSTAT, 2006).

For the simulation of agricultural processes (e.g. plant growth or nutrient demand), data on the applied technology, application dates or rates would be most preferable. On a European level such data is supposed to be collected for the so-called LUCAS (Land Use/Cover Area Frame Statistical Survey) inventory phase II. This databank was not accessible to INSEA. By surveying techniques, information on crop rotations, crop specific seeding technology, fertilizer amounts, fertilizer types, and so forth is collected for LUCAS and provided on an 18 km grid basis (geo-referenced point database). For EU-EFEM, this gap could be closed, although only partially, by a German database called KTBL. This contains practice-based data on crop level (e.g. on diesel consumption, work force, etc.) and attributes agricultural activities to certain periods, but is only site-unspecific.

For the biophysical models within the INSEA network, but partially also for EU-EFEM, biophysical data like topographical parameters from GTOPO30, weather parameters from 1992 to 2002 from a MARS (Monitoring Agriculture with Remote Sensing) meteorological subset, land cover data from CORINE and PELCOM were managed. These data were mainly provided by the Joint Research Centre (JRC) in Italy. The resolution of the topographical data is approx. on a 1 km grid basis, weather data on a 50 km grid, and land cover data on a 1 km grid. Soil information consisting of information on topsoil composition, soil depths, cation capacity, and organic carbon amongst other data is on a 10 km grid basis (ESDBv2 program of the JRC). Geographical data are from the geographical information system of the European Commission, GISCO, on a NUTS-II level. In order to fit the spatial delineations among databases, the data were visualised and processed by feeding geographical GISCO data into a GIS programme.

Although the main data inputs for the biophysical models were on a 1 km grid, a new modelling unit was defined for the EPIC model on which it is more realistic to setup a management scenario than on a 1 km grid. This new unit is the so-called Hydrological Response Unit (HRU) (Schmid et al., 2004). The definition of HRUs shall bring down the number of modelled units to a reasonable size, but portray the heterogeneous landscapes. The four essential data components of EPIC, which are soil, climate, technology, and management, are basically reflected in the definition of HRUs. These parameters and other parameters of landscape which are relatively stable over time and hardly adjustable by farmers were selected to create the HRUs. The parameters are elevation (4 classes), slope (7 classes for grassland and 5 for arable land), soil texture (6 classes), soil depth (4 classes), and stones in subsoil (3 classes). Climate is represented by daily weather data (precipitation, daily minimum and maximum temperatures, and solar radiation). Technology and management are divided, in accordance with INSEA premises, into three classes of soil management: conventional tillage, reduced tillage, and no-till.

3.2.2 The Biophysical EPIC Model

Characteristic to biophysical models is the simulation of physical or chemical processes of the atmosphere, biosphere, or pedosphere. In agricultural and forestry research, such models help to understand and predict plant growth, plant yield, nutrient or carbon cycling. Research questions which have recently come to light, like the quantification of carbon stocks and the depiction of carbon dynamics, have resulted in a growing demand for this type of models. Within the INSEA network the

Environmental Policy Integrated Climate (EPIC) model, formerly Erosion Productivity Impact Calculator, has come into use. Its ability to depict the variability of crop production, carbon inputs, soil organic carbon, and N-cycling over a range of soils, cropping systems, and climatic conditions guaranteed its application within INSEA.

Originally developed by a team of the USDA (United States Department of Agriculture) in the early 80's to assess the status of the United States soil and water resources, it has been continuously expanded and refined to allow also for the simulation of agricultural management alternatives and effects thereof on nitrogen, phosphorous and organic carbon among others. Meanwhile EPIC has experienced world-wide dissemination (EPIC, 2006). Since its development, EPIC has been applied in drought assessment, soil loss tolerance assessment, water quality analysis, global climate change modelling, etc. in the majority of countries. Site-specific effects of management decisions on soil, water, nutrient, and pesticide movements and their combined impact on soil loss, water quality, and crop yields are among the simulated processes. Through these processes, a high degree of detail is achieved by the simultaneous inclusion of a variety of processes including backward and forward correlations. For example, soil organic matter development not only depends on plant growth, but also plant growth depends on soil organic matter. Over time, the original version has been supplemented by modules for the simulation of C- and N-routines interacting directly with soil moisture, temperature, erosion, tillage, soil density, leaching and translocation functions (IZAURRALDE et al., 2006).

EPIC can be operated on a daily time step requiring high quality input data on weather, tillage, seeding and harvesting dates. Management options include crop rotations, crop/grass mixes, tillage operations, irrigation scheduling, drainage, liming, grazing, burning operations, manure handling, fertilizer and pesticide application. The adjustment of model parameters requires profound expert knowledge and/or help from alternative data sources like phenological data e.g. to derive optimal seeding and harvest dates. Help from alternative data sources was sought. In the INSEA framework phenological data was joined from the MARS (Monitoring of Agriculture with Remote Sensing, provided for by the Joint Research Centre (JRC)) crop calendar which is on a 50×50 km grid in order to date agricultural field activities (e.g. seeding or harvesting) in the biophysical EPIC. For more details on EPIC and on its steering data see Schmid and associates (SCHMID et al., 2004). As previously mentioned, EPIC is run on the modelling units of HRUs. In order to limit the computational effort, simulations were only made for certain likely crop rotations. As it was intended to reflect real crop rotations, the predefined crop rotations per HRU were deduced from NewCronos data on crop shares (see BALKOVIC et al., 2007).

3.2.3 Model Compound

With models becoming not only more and more sophisticated but also complex, the demand for integrative interdisciplinary solutions has been rising continuously. "Super-models" simulating various sectors or analysing a number of research questions from different fields require large well-rehearsed interdisciplinary teams for development and analysis, and exhaustive model effort. The coupling of smaller models offers an alternative to such super-models.

3.2.3.1 Coupling

The expectation that led to the development of the economic models of the INSEA-project was close cooperation and mutual data exchange. Through this cooperation and exchange, the farm level models should benefit from simulated market reactions of the market models (partial equilibrium models) and incorporate them to their scenario analyses, thus balancing out the disadvantage of model exogenous sales and purchase prices. An older but remaining challenge to EU-EFEM is the integration of ecological parameters. The simulation of ecological processes is often complex and can best be done within biophysical models.

Trying to integrate all kinds of simulations within one model is often impossible due to the incompatibility of models (model approaches). It often is not desired either, because the interpretation of results becomes more difficult and the feasibility of computations would be curbed. A way out of this dilemma is the coupling of different models. In this way, the central question is about the modalities of the coupling and the subsequent creation of adequate interfaces.

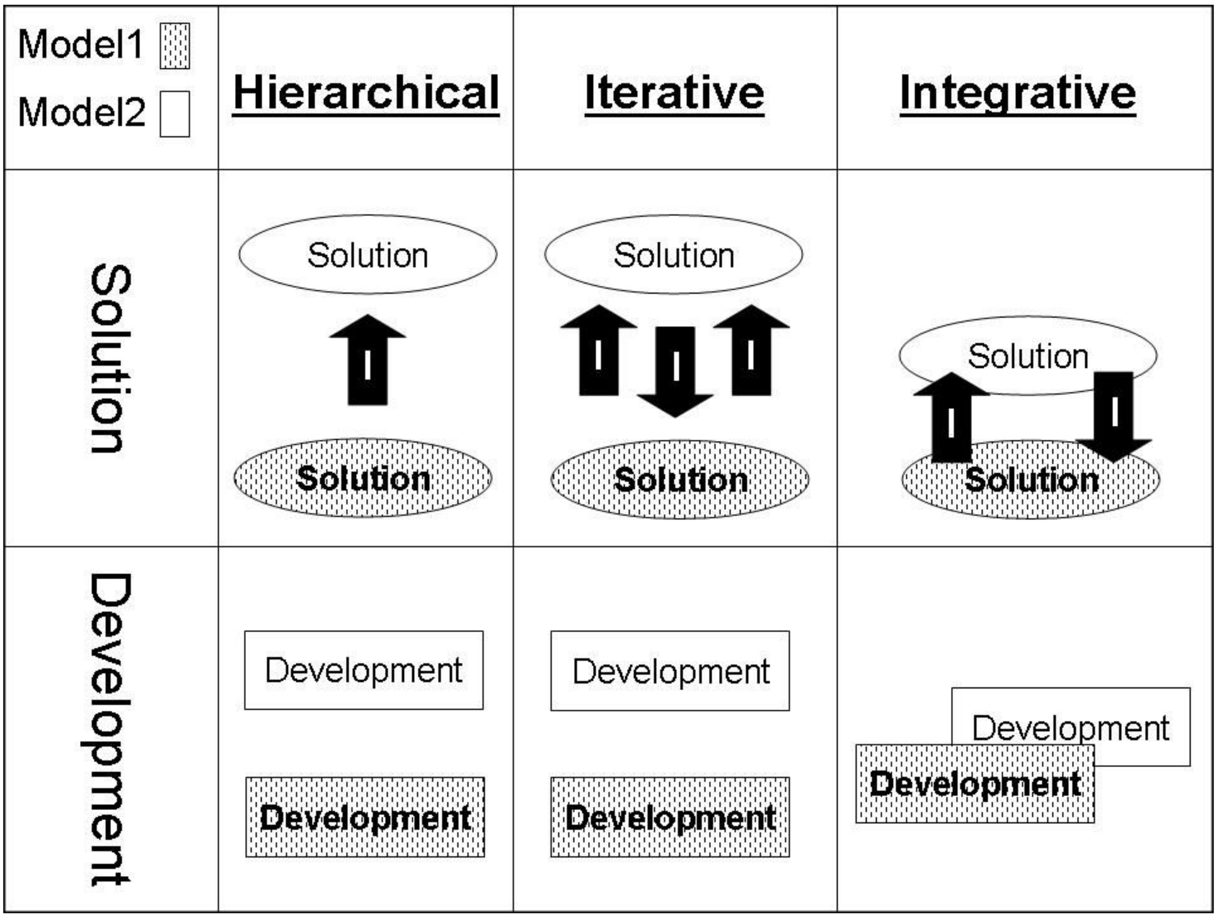


Figure 3: Coupling Methods (Compared for the Two Model Case)

Along with the depth of integration, a distinction is made between hierarchical, iterative, and integrative coupling. Hierarchical refers to the hierarchical order maintained during the solving process and the data exchange. The direction of data exchange and transfer of results is one-way. In hierarchical coupling, models are developed and solved independently from each other. In iterative coupling, in turn, the exchange is mutual, though models are still elaborated and solved independently. Solving and data exchange happens multiple times until an equilibrium condition or similar establishes. Integrative coupling, however, means the simultaneous solving of components. Therefore, relevant modules are to be integrated into one central model. In difference to iterative coupling, integrated coupling not only achieves an approximation to the optimum, but actually achieves the optimum. An illustrative comparison of all three methods is presented in Figure 3, which shows the conditions for development and solving.

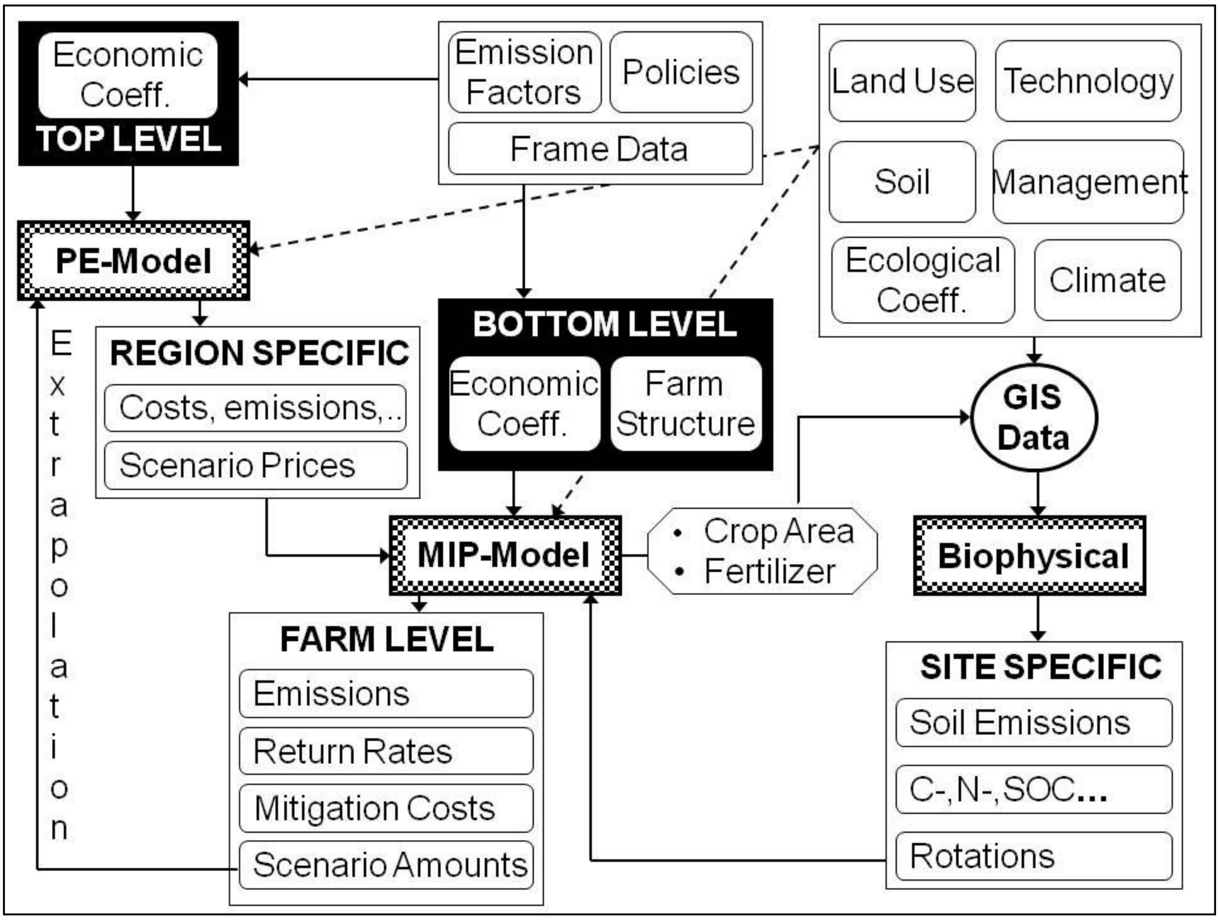


Figure 4: EU-EFEM Linkages within INSEA

Legend: PE: Partial Equilibrium, MIP: Mixed Integer Programming, GIS: Geographic Information System.

For the coupling of EU-EFEM and other models of the INSEA-project, integrative coupling was not an option, since the relevant models had already been developed. So, the choice was between hierarchical and iterative coupling. Both ways could come into application, since the difference is unilateral versus bi-(multi-)lateral exchange. Figure 4 shows the theoretical and generalised set-up of the INSEA-compound seen from EU-EFEM's perspective (the MIP-model). In the case of INSEA the biophysical model is EPIC and the Partial Equilibrium (PE) model is EU-FASOM, a European version of FASOM (see section 3.1.3).

Between EPIC and EU-EFEM a bilateral dataflow takes place; both are on a regional basis. The flow from EPIC to EU-EFEM has to be aggregated, from site-specific respective HRU specific data to NUTS-II regions (intersected via GIS). The data provided from EPIC incorporates, among other elements, soil emissions, carbon stock initial values, or soil organic matter formation. The flow from EU-EFEM to EPIC can only be on the regional NUTS-II level. A disaggregation from this rougher to the finer HRU resolution is not possible. Yet EPIC often only disposes of data on even rougher regional resolution, like general manure application rates. Furthermore, EU-EFEM can provide scenario specific data to EPIC.

The coupling between EU-EFEM and EU-FASOM has been conceived, but has not been realised, since the development of EU-FASOM was not ready at the time the coupling was contemplated. In theory, the most appropriate way to couple EU-EFEM and EU-FASOM would be through iterative coupling. Mutually exchanged information blocks could be regarding the calibration of total emissions or mitigation costs. For EU-EFEM, desirable data includes market reactions or price predictions. In return, EU-EFEM could pass back scenario amounts in reaction to EU-FASOM scenario prices.

3.2.4 Integrating Biophysical SOC-Simulation Values

In this section the simulation of the Soil Organic Carbon (SOC) by EPIC and the integration of the simulation results to EU-EFEM will be described. The EPIC simulations feature site-specificity, with respect to HRU-specificity, accounting thus for (natural) production conditions like soil type and weather. EPIC simulations are done for three alternative tillage managements (1 conventional and 2 conservational tillage schemes) and two alternative managements of plant residues. All management alternatives matter as to SOC accumulation. Apart from SOC simulation results, also simulated yields are in part transferred to EU-EFEM (see section 3.3.3).

The concept of the HRU as modelling unit for the biophysical EPIC (see section 3.2.1) is based on the four data components soil, climate, technology, and management. For the simulation of SOC in EPIC, a fifth component is added: crop rotation. Incorporating crop rotation as a parameter in the SOC simulation better depicts soil organic matter dynamics. As an alternative to these SOC simulations, crop unspecific values on a per hectare basis could be taken, or single crop specific values like those provided by the Cross-Compliance regulations amended with the 2003 reforms of AGENDA 2000 (see section 3.1.2). But both only paint a static picture independently of preceding crops, i.e. cultivation history or crop rotation.

The data transfer from EPIC to EU-EFEM is via an ad hoc conceived interface which intersects EPIC's spatially explicit data with data on its regional representation per NUTS-II regional unit (according to Figure 4, previous section). In order to achieve a manageable data level and to limit the number of necessary EPIC simulations, the soil parameters in the wider sense were classified into: three slope classes (0 - 6%, 6 - 15%, >15%), two altitude zones (0 - 600 m, >600 m), two stoniness classes (0 - 25%, >25%), one soil depth class, and five soil types (coarse, medium, medium fine, fine, very fine)[27].

With the integration of the rotation specific SOC values into EU-EFEM, EU-EFEM also had to simulate crop rotations. Integration is through a binary variable which is the only practicable way, although it carries the disadvantages of longer solving time, dual solution, and computational performance. Each rotation is defined by a certain upper and lower share of the total farmed area which a certain crop or crop group may occupy. Normally, in linear programming models (like EU-EFEM) only rather wide rotational limits are integrated as constraints within which the model freely combines crops. Here, in contrast, a number of sets of different rotational limits are integrated. These sets of rotational limits have to be mutually exclusive. This mutual exclusivity is necessary for a binary variable, i.e. the model has to decide for one crop rotation what the upper and lower limits for each crop or crop group will be that have to be kept.

Mentioned in section 3.2.2, only a finite number of crop rotations per HRU (deduced from empiric cultivation history) were simulated by EPIC. This means that for a change of crop rotation that goes beyond the historic variation in crop rotations, no EPIC simulation results are available. For the production of the EU-EFEM reference situation this suffices, since both models start from the same land use scheme. For the scenario analyses, however, scenario assumptions can shift the competitiveness of production activities beyond the historic crop rotations. This means that simulations should cover the whole range of possible crop rotations at least as far as noticeable differences between rotations as to SOC values manifest. Since no additional EPIC simulations were available, an alternative approach was chosen. The alternative approach reduces the specificity of crop rotations to HRUs by applying several aggregations of original HRU specific EPIC simulation results.

---

[27] According to sand and clay contents (see SCHMID et al., 2005).

Within EPIC, crop rotation was represented by a sequence of single crops during a ten year period. The range of crops in EPIC is the same as in EU-EFEM. Now, the crop rotations for EU-EFEM had to be defined in such way that they could be built on EPIC simulations. This was the starting point for a first aggregation of EPIC simulations. For the definition of rotations in EU-EFEM, single crops were grouped according to their impact on SOC, which is the parameter of interest for this modelling exercise. The main differences with respect to SOC development, which falls together with soil humus development, are assumed for the four groups: (1) cereals, (2) hoed tuber crops (e.g. beet or potato), (3) maize, and (4) humus accumulating crops (including set-aside). A resolution of 20%-steps for crop shares (i.e. discrete variable)[28] was contented by the applicants of EPIC and EU-EFEM in the current framework. Because of this classification of rotations according to crop groups, the same rotation could be found in several HRUs.

Yet the number of rotations per region including several HRUs was reduced. Still higher flexibility was aspired to for EU-EFEM, which required a second aggregation. This second aggregation does not aggregate rotations, but HRUs. Similarities between the characteristics defining a HRU were considered a joining criterion for aggregation. How the EPIC characteristics of HRUs got carried through in newly-defined EU-EFEM classes can be seen in Table 12. It illustrates which characteristics are merged and opposes the number of EPIC classes to merged EU-EFEM classes (e.g. 7 EPIC slope classes were merged to 3 EU-EFEM classes).

Table 12: Aggregation of EPIC Classes for EU-EFEM

HRU Criterion	**EPIC Classes**	**Aggregation**	**EU-EFEM Classes**
	(Number)	(Identure Numbers)	(Number)
soil texture	5	1, 2, 3, 4, 5	5
altitudes	4	1+2, 3+4	2
stoniness	3	1+2, 3	2
soil depth	4	1+2+3+4	1
Slope	7	1+2, 3+4, 5+6+7	3

With the two aggregations (first: original EPIC crop rotations; second: HRU characteristics), the major rotation and site specific conditions are still captured, while

---

[28] Example: Rotation 1): 0% cereals, 0% maize, 20% tubers, 80% humus crops, rotation 2) 0% cereals, 0% maize, 40% tubers, 60% humus crops. Deviations are allowed up to ±10 percentage points.

the accuracy of EU-EFEM is increased by offering several and not only one possibility for site-specific crop rotations with correspondent EPIC SOC values.

In addition to the current crop, the crop rotation (cultivation history), and the site-specific conditions, management is also considered to be an important factor for SOC development. EPIC considers three types of tillage as management options. But additionally the treatment of plant residues is understood as an important factor, since it is the main driver for organic matter input into soils if residues are left on a field. For reasons of computational feasibility, only two extreme cases are simulated by EPIC: (1) all residues are left on the field, or (2) all residues are taken from the field. In this study a linear trend is assumed for the SOC development between both points. Although desirable, the organic matter input from organic fertilisation was not simulated by EPIC for different scenarios. Only the amounts calculated by EU-EFEM for its reference situation were assumed in EPIC. Although EU-EFEM is not calibrated as to crop specific fertilisation (the nitrogen cycling is simulated on a plot level, see section 3.3.3), this crop specific attribution and the direct link to regional animal capacities makes this data the best available.

The high specificity of EPIC's simulations and the integration of delivered SOC-values into the economic surrounding of EU-EFEM is a powerful means in terms of accuracy and computational feasibility, as well as in terms of political and economic scenario analyses. However, there are cases which speak for the application of less detailed general SOC-values. For example, policy programmes is such a case. Typically these are designed to treat (groups of) farmers equally, independent of soil types found in their fields or other uncontrollable factors.

A policy programme which aims at SOC-accumulation among other and generally means to promote sustainable agriculture by binding subsidies to environment services is the Cross-Compliance programme (as already mentioned above, the programme was imposed by the 2003 reforms of the CAP). SOC accumulation is addressed in the form of humus accumulation. In this context fixed factors that account for humus formation are formulated. They express the change of humus stocks per hectare due to the cultivation of a certain crop. Yet the cultivation alone affects humus stocks, but also crop residues in case left on field for decomposition and not withdrawn. The latter correlation is not per hectare but per weight units of residues left on field.

Table 13: Humus Accumulation Factors in Cross-Compliance Regulation

Crop	**Related to Cultivation**	**Related to Residues Left on Field**	**Manure**	**Related to Manure Spread on Field**
	(kg/ha)	(kg/dt DM)		(kg/dt DM)
cereals	-280.0	10.0	liquid	12.0
non cereals*	-280.0	10.0	solid	15.0
maize	-560.0	10.0		
sugar beet	-760.0	0.8		
potato	-760.0	0.8		
green clover	600.0	0.0		
(fall) fallow[29]	180.0	-.-		
catch crop	120.0	-.-		

**non-cereals: includes legumes, clover-like fodder plants, and hoed crops (like maize or beets, except grain maize).*
Source: BMVEL (2006), German version of the Cross Compliance Regulation.

In the Cross-Compliance regulation the cultivation of crops either entails humus consumption or accumulation, according to the type of crop. Residues left in the field, in contrast, always contribute to humus accumulation (compare Table 13). Farmers participating in the cross-compliance programme have to calculate the humus balance for their farms by means of a simple calculation. They multiply the number of hectares under each crop with the crop specific humus factor. This procedure is for the main crop. For the by-product (crop residues), the quantity of by-products in decitons is multiplied with the residue specific humus factor. The cross-compliance programme stipulates maximal deviation from an equilibrated balance at ±0 kg per farm.

3.3 Components of the Farm Type Model

In this section EU-EFEM (European Economic Farm Emission Model) will be described as a farm type model, along with the structural implications that arise from such a model type. The section focuses on “core” modules before amplifications in research scope and in data management will be described in the next section.

3.3.1 Agricultural Policy

European agricultural policy is complex comprising of different schemes of payments, quotas, and ecological regulations (as described in section 3.1.2). In the simulation of

---

[29] Natural regeneration of vegetation

EU agricultural policy two structural elements are to be considered: first, the existence of farm level regulations and second, the existence of regulations of a national level. Prominent farm level regulations are limits of per hectare livestock stocking density. Prominent national regulations are derogations of payments proportionate to the rate of overshoots of national ceilings. Simulating such national regulations is not possible in models based on a bottom-up approach like EU-EFEM. Alternatively, an approach will be introduced that is applicable in bottom-up models while considering the historic fulfilment of national ceilings, a case in which actually the simulation in a top-down model would be indicated. In doing so, real payment flows (i.e. with respective derogations) can be approximated in addition to the simulation of farm level regulations one-to-one.

In EU-EFEM, the mentioned approach is only applied to the animal sector. In the plant production branch it is omitted since national ceilings (Council Regulation (EC) No 1782/2003 and Council Regulation (EC) No 118/2005) and implementation choices are not as numerous as in the animal production branch and the significance to the results is thus smaller. This means that national quotas for plant premiums like the energy crop payment limited to 1,500,000 ha are disregarded.

Structurally, in EU-EFEM agricultural policy is simulated on farm level. It was assumed that the number of contemporary stables places represents an upper limit which will not be expanded. The value of the animal premiums is not copied from the agricultural policy regulation, but it is taken instead from the recent accountancy data. In the accountancy data real payment flows are indicated, i.e. national derogations to the premiums indicated in the agricultural policy regulation, which practically are maximum premiums, are in case of overcalling of premiums already implied. In the accountancy data the payment flows are given as total farm payment, but specified to payment category, so that the division by the number of qualified animal heads yields the premium value per animal head[30].

Now, drawing back on the assumption that the number of stable places from the accountancy data represents the upper limit for stable places, only not-using stable places can change the value of a single animal premium. The “virtual farmers” of the model thus decide whether to use all stable places or to have unused capacities. It is assumed that large unused capacities will not be found for the analysed scenarios.

---

[30] An average over several years is calculated.

This approach will only deliver more accurate simulations in case the overshoot of national ceilings is more likely than the not-using of stable places. For EU-EFEM, no cross-check between unused capacities and national ceilings is executed.

In the simulation of agricultural policy, both, in the animal and the plant production branch, the complexity of policy regulations is reduced. In the plant production branch, the national caps to the premiums are disregarded. In the animal production branch, farm receipts are reduced by fixed values in case of unused capacities regardless of the level of utilization of national ceilings. It must be noted that apart from this structural simulation problem, the deduction of unused capacities in animal production carries further inaccuracies since the definition of premium categories in the policy regulations could not fully be matched with the definition of animal categories in EU-EFEM.

3.3.1.1 Integration of the AGENDA 2000 Regulations

The AGENDA 2000 regulations are integrated to EU-EFEM as valid during the years 2000 to 2001, i.e. the period covered by the model's reference period[31]. In line with the above described approach, coupled payments are integrated to EU-EFEM as the average of the values given in the accountancy data for 2000 and 2001. Premiums that are not claimed by the model due to a simulated reduction of production are deducted with the named value and not with the average value. This is only an approximation to reality but, again, in a farm level model like EU-EFEM, the overall use of the national ceilings cannot be simulated. The set-aside regulation is also simulated, reflecting the state of the AGENDA 2000: the minimum and maximum level of set-aside are defined by policy annually for the minimum (compulsory) and fixed permanently for the maximum (voluntary).

The coupled payments in the COP-sector draw on the principle of historic yield. The data on historic yields were provided by the CAPRI (2006) network on a regional level and for all EU-15 member states. The latest values of historic yields and historic payments were applied to EU-EFEM. The historic yields have been fixed by policy and will remain unchanged with the replacement of the AGENDA 2000 with the 2003 reforms.

---

[31] All parameters that are from the FADN accounting data are for the years 2000 to 2003.

3.3.1.2 Integration of the Reformed AGENDA 2000 Regulations

Under the 2003 reforms of the AGENDA 2000 (section 3.1.2), the single farm payment (SFP) was introduced, i.e. a farm specific payment whose value is deducted from premiums obtained during a previous reference period. For the purpose of determining the value of premiums received during the reference period (2000 - 2002), in EU-EFEM, as a first step, a reference run is initiated. Its result is stored to an external file. In the second step, EU-EFEM is started, drawing on these previously stored data, in terms of the reformed AGENDA 2000, the so-called "*historic receipts*". For the reformed AGENDA 2000, EU-EFEM performs the (national or sometimes regional) derogations to the historic payment stipulated with the reforms (compare Table 10), thus obtaining the farm specific SFP.

The regulations of the sugar market were implemented to the model as valid by the year 2013, with the fixed institutional price of 26.29 €/t of beet and 60% compensation for price reduction with respect to the (national) price before the 2005 sugar market reforms being merged into the SFP (*COUNCIL REGULATION,* 2006)).

3.3.2 Livestock Production

In many regions, farming and farm income are dominated by livestock production. Livestock production can be as independent production branch importing all necessary imports from outside to the farm or it can be an integral part of a farm in which inferior plant products are refined to valuable final products like milk or meat. Depending on the relation between livestock production and other production branches, the availability of land to receive animal excreta and thus the threatening of the environment is different. While in extensive production zones, animal excreta are appreciated for their fertilizing value, they might represent a waste product threatening groundwater or air quality. This, different natural production conditions, and consumer preferences created a quite differentiated picture of livestock production across the EU reflected in stocking densities, housing types, keeping conditions, animal types and final products. A one-to-one simulation of the whole range of livestock production conditions seemed too ambitious for EU-EFEM's scope. However, the intention was to roughly capture the main structures by the formulation of three disassociating dimensions of animal populations (animal types, animal ages, and performance levels) and by the specification of main on-farm ecological and economic parameters (housing, feeding, manure accrual, and costs and revenues).

3.3.2.1 Animal Categories

Animal groups within EU-EFEM are: (1) cattle, (2) pigs, (3) poultry, (4) sheep, and (5) goats. These five groups are very rough and insufficient to reflect the diversity of feeding requirements, emission rates, or sales prices. A further classification of animal groups is thus desirable. The applied criteria for further classification are 1) animal age and 2) keeping purpose (breeding, fattening, or milk production). In Table 14 it is shown how these classifications are finally reflected in production activities and sales products. For the analysis of gross margins, living weights were defined for each class, since revenue is often the average carcass dressing percentage multiplied by the living weight and the meat price.

Table 14: Specification of Animal Products in EU-EFEM

Product	Specification	Sex	Final Weight (in kg)	Final Age (in d)
dairy cow	milk breed	♀	560	>730
suckler cow	meat breed	♀	650	>730
fattening calf	milk breed	♀, ♂	140/ 140	111, 107
	meat breed	♀, ♂	170/ 180	125, 128
baby beef	meat breed	♀, ♂	320/ 350	357, 357
	milk breed	♀, ♂	320/ 325	489, 466
fattening bull	meat breed	♂	600	539
	milk breed	♂	540	480 - 553
fattening ox	meat breed	♂	570	608
fattening heifer	meat breed	♀	480	509
	milk breed	♀	450	527
dairy heifer	milk breed	♀	560	833
suckler heifer	meat breed	♀	560	833
breeding bull	milk breed	♂	870	855
Pigs	breeding	♀	175	338
	fattening	♀, ♂	120	220, 220
	piglet	♀, ♂	20	49, 49
mother sheep	incl. lamb	♀	70	>365
mother goat	incl. goatling	♀	75	>365

Despite this categorisation into sales products, two further categorisations had to be added. The first of these needed to be added because the capacity restriction of animal production (i.e. stable places) is deduced from the FADN data set. The second is necessary because the simulation of emissions is mainly based on IPCC parameters. Each data set, FADN and IPCC, comes along with its own categorisation of animals. For the purpose of analysing all three dimensions at a time (sales products, capacity restriction, and emissions) EU-EFEM uses proper conversion factors[32].

Paying tribute to the enormous production diversity in the EU, EU-EFEM analyses several production intensity levels, at least for the most important animal groups, cattle and pigs. Dairy cows' performance levels are expressed as milk yield[33] per year, ranging from 4,000 - 10,000 kg. The fattening of male cattle is specified for three classes of different daily increments. In pig production three litter sizes are modelled with 16, 18, and 22 piglets reared per year.

3.3.2.2 Animal Housing

Animal keeping systems are characterised by housing type and manure storage systems. Animal housing in extensive systems is usually outside during the larger part of the year in the EU. Intensive animal keeping is mainly indoor production. With the housing type defines the range of potential storage systems. Housing systems with slotted floors feature liquid manure systems (confinements below the stable, lagoons, tanks, or direct spreading), animals kept on deep litter produce solid manure that is stapled outdoor normally, and grazing animals leave excreta on the grazed meadows.

This logic is also portrayed in the model. Since there is no one-to-one link between housing and manure management system, and due to the lack of correspondent statistics the attribution of animals to a system remains difficult. In the face of sometimes contradictory statistics on housing and manure systems in the EU, data from several sources was merged in EU-EFEM[34].

3.3.2.3 Animal Feeding

The simulation of feeding of animals is not uniform for all simulated animal groups, but orientates by the type and by the choice of feedstuffs usually offered. In the following the feeding of productive animals is shown, while for breeding (growing) animals feeding will not be described. This seemed too expensive and generally the feeding of growing animals is not different. It is orientated by the feeding

---

[32] Conversion factors are oriented by the keeping duration defined for animal categories.

[33] Fat Corrected Milk Yield (FCM): the values are based on default fat and protein contents.

[34] 1) National Inventory Reports (NIR) to the UNFCCC in the context of the Kyoto Protocol's reporting obligations (UNFCCC, 2005). 2) RAINS-(Regional Air Pollution Information and Simulation) project (KLIMONT and BRINK, 2004).

recommendations per unit of body weight and daily increments so that the different stages of growth can be described with their own feeding functions. The interested reader should consult the relevant literature (for example, KTBL, 2005 or KIRCHGESSNER, 1997).

The integration of poultry feeding is done in the simplest way, since poultry is normally fed concentrated feedstuffs and the choice is not that large: cereal maize mixtures are the most appropriate. The minimum requirements of the animals are satisfied by this concentrated feedstuff. The consumption is:

a) 47 kg/a per laying hen, and
b) 58 kg/a per 7.2 broilers.

All other animal groups are offered the combination of feedstuffs from which to select involving feed concentrates as appropriate. The formulation of feed requirements is by defining minimum and maximum nutrient needs and maximum quantities. The model then decides upon the optimal combination of feedstuffs that fulfil these requirements. Also the simulation of livestock emissions benefits from doing so, since in some emission estimates certain feed components are seen as being directly linked to emissions.

In pig feeding, the most limiting nutrients are energy, protein (raw protein), and lysine (amino acid) (see Table 15). Further, digestibility is an important characteristic, giving expression to the ration's energy density. Digestibility of pig rations is controlled by formulating a maximum fibre content of 25% of Dry Matter (DM). In pig feeding, the energy requirements are in units of Metabolisable Energy (ME).

Table 15: Minimum Feeding Requirements of Breeding Swine (per Stable Place).

Intensity	**ME (1000 MJ)**	**Raw Protein (kg)**	**Lysine (kg)**	**Dry Matter (kg)**
int_1	12.0	130.8	6.0	1,329.0
int_2	12.4	136.2	6.3	1,329.0
int_3	12.7	140.5	6.5	1,290.0

Source: own estimate based on KIRCHGESSNER *(1997), and* KTBL *(2005).*

Compared to pig feeding, the feeding of ruminants is more complex. This is also reflected in the number of equations available to calculate the feeding requirements of ruminants. For cattle, this study draws on a calculation proposed by KIRCHGESSNER (1997). He expresses energy requirements in MJ of Net-Energy-Lactation (NEL) and considers protein (raw protein), fibre (raw fibre), and dry matter as limiting minimum factors to nutrition. For dairy cow feeding, the last three factors are also considered as maxima, since exuberant nutrients burden the animals' metabolism or surpass physical restrictions like the stomach's volume. For example, highly lactating dairy cows react sensitively to exuberant proteins, whose derivates have to be metabolised and excreted by the kidneys. Fibre is considered by the author, although it is not a nutrient, since the ruminants' digestion is with different stomachs, of which each features a specific bacterial flora, and for these stomachs fibre helps to maintain an equilibrated condition.

The minimum requirements in dairy cow feeding like indicated by KIRCHGESSNER are shown in Table 16. Not shown in the table are the maximum requirements applying only to protein and dry matter. They are calculated as:

$$\text{Protein\_max (g)} = 15 \times \text{NEL(MJ)}/0.6$$

$$\text{DryMatter\_max(kg)} = 18 + (\text{MilkYield(kg)}/1{,}000 - 4) \times 0.5$$

Table 16: Minimum Feeding Requirements of Dairy Cows (per Stable Place).

Milk Yield	**NEL**	**Raw Protein**	**Raw Fibre**	**Fibre**	**Dry Matter**
(kg)	(1000 MJ)	(kg)	(kg)	(kg)	(kg)
4,000	27.6	539.7	930.1	516.7	5,167.2
5,000	30.8	624.7	966.8	537.1	5,371.2
6,000	34.0	709.7	1,002.3	557.0	5,570.1
7,000	37.2	794.7	1,037.5	576.4	5,764.0
8,000	40.4	879.7	1,071.5	595.3	5,952.8
9,000	43.6	964.7	1,104.6	613.6	6,136.5
10,000	46.8	1,049.7	1,136.7	631.5	6,315.2

Source: own calculations based on KIRCHGESSNER *(1997).*

Sheep feeding is based on feeding recommendations for mother sheep (living weight 70 kg), including 1.3 lambs. The minima and maxima are shown in Table 17. Goat feeding is presented for an animal of 75 kg, and of 3 kg of daily milk yield (during lactation). The upper limits for the nutrient uptake are based on the author's estimated values.

Table 17: Feeding Requirements of Sheep and Goats (per Stable Place).

	Minima			**Maxima**	
Animal	**ME**	**Raw Protein**	**Dry Matter**	**Raw Protein**	**Dry Matter**
	(MJ)	(kg)	(kg)	(kg)	(kg)
sheep	8,180.0	109.5	766.5	175.2	876.0
goat	9,130.0	109.5	912.5	175.2	1,095.0

Source: PRIES *and* MENKE *(2006), and* LFL BAYERN *(2006).*

3.3.2.4 Animal Excreta

The amount and the composition of manure are the two essential factors in the simulation of nutrient cycling on farms. Generally speaking, both depend on the animal's type and age, and the composition of the feeding ration, water uptake, and the mixing with litter. The latter has a large effect on the amount and composition of manure, but is mainly attributable to the type of housing (e.g. litter based system vs. slotted floor). Nitrogen is the most important nutrient in plant production, but is also contained in significant amounts in animal excreta. In the technical literature nitrogen excretion rates per animal are given and values are copied to EU_EFEM, where slurry, solid manure, and sullage are categorised (see Table 18). Excretion rates of other nutrients than nitrogen are described in Annex 6.

Table 18: N-Excretion Rates in the Literature for the EU-15

	N-Excretion Rate			**Conversion Factor**		
Animal Type	**Maximum**	**Minimum**	**EU-EFEM**	**Slurry**	**Solid**	**Sullage**
	(kg N/ stable place)			(dimensionless)		
Cattle:						
dairy[35]	178.20	71.40	*formula*	1.00	3.80	0.29
fattening	54.00	37.00	45.00	1.00	3.80	0.20
breeding	54.00	37.00	30.00	1.00	8.30	0.27
Pigs:						
sows	36.00	23.70	23.7 - 36.0	1.00	---	---
fattening	13.00	11.00	10.0 - 13.0	1.00	---	---
breeding	15.00	6.20	11.0 - 12.4	1.00	---	---
Poultry:						
fattening	0.58	0.58	0.58	1.00	---	---
breeding	0.51	0.51	0.51	1.00	---	---
Others:						
sheep incl. Lamb	18.30	18.30	18.30	1.00	3.70	0.20
goat incl. Lamb	14.80	14.80	14.80	1.00	3.70	0.20

** Per 100 heads.*
Source: KTBL (2004); Krayl (1993); Kazenwadel (1999); and Klimont and Brink (2004)

---

[35] As far as to model range of milk yields. Not surveyed values like for other animals.

For all animal types except dairy cattle, it is deemed sufficient to specify excretion rates according to animal type and age class regardless of the feeding ration. Thereby national values are copied to EU_EFEM in order to reflect the magnitude of values found in technical literature[36]. The difference between the lowest and highest excretion rate of breeding pigs, for example, is in excess of 100% (6.2 kg N compared to 15.0 kg N).

From an analytical point of view, it would be most desirable to simulate excretion in dependency to feeding. In the literature a similar relation has only been found for dairy cows in the RAINS dataset where a regression with the single factor milk yield was drawn (see Formula 4). The validity of the regression is mentioned for the whole range of milk yields found in the EU-15.

Formula 4: Approximated Dairy Cow Nitrogen Excretion (kg N/ stable place)

$$\boldsymbol{Nx} = 0.0178 \times \boldsymbol{MY} + 0.2271$$

with:

MY milk yield (kg/animal/yr)

3.3.3 Plant Production

Until farmers can harvest their fields, many factors have to be optimised in order to maximise profit. Many of them feature an economic and ecological component. EU-EFEM accounts for both. The optimisation of the total farm gross margin in the programming model simultaneously provides for the optimal production intensity, optimal production plan, and minimal cost combination (like other linear programming models). Ecological aspects are integrated in the form of restrictions or are simply quantified without restricting the model.

For reasons of complexity and computational feasibility, simplifications were necessary as to management dates (seeding date, fertilisation dates, harvest date, etc.) that are influenced by weather and availability of farm work. However, EU-EFEM features the differentiation of model periods according to rough seasonal diversities. The simulated five periods are:

---

[36] KLIMONT and BRINK (2004) conducted a survey among scientific networks within the RAINS-project and compared respective supplemented results by reviewing secondary data. This country specific data was intersected with German datasets (BUNDESGESETZBLATT, 2006; and KTBL, 2005).

P1: March,	*P4: September - October,*
P2: April - July,	*P5: November - February.*
P3: August,	

3.3.3.1 Management Alternatives

Three management alternatives as to tillage are integrated into EU-EFEM:

1) Conventional tillage: ploughing,

2) Conservational tillage: mulch seeding, and

3) Conservational tillage: no-till.

Conventional tillage is with the plough. The depth of ploughing depends on the soil type but involves full soil inversion. Further, also one or more steps of soil preparation of the top soil are applied depending on the cultivated crop. Conservational tillage which is analyzed as a means to achieve SOC-accumulation (see section 2.3.1) is reflected by the two alternatives “mulch seeding” and “no-till”. In mulch seeding soil disturbance is reduced and done with mulching equipment. At least 30% of the surface remains covered by mulch at planting, and full soil inversion is not practiced according to the IPCC definition (IPCC, 2006b, p. 5.19). In no-till soil disturbance is only marginal occurring during seeding (~ most upper 5 cm). Special technologies are necessary to handle stubble and other above ground plant residues.

Conventional tillage is the default tillage scheme and as such unrestricted in the model. Conservational tillage is restricted by two limitations. First, in the reference situation no conservational tillage is allowed. It is recognised that the assumption of zero conservational tillage for the reference situation is a rather strong restriction against significant shares indicated in empirical data (see Table 19). Second, the relation between no-till and mulch-seeding is bound within the limits 0.0:1 to 0.5:1. The underlying argumentation is that mulch seeding is regarded a precursor technology to no-till[37]. So farmers can gather experience in mulch-seeding before switching to no-till.

---

[37] Since EU-EFEM is not a dynamic model, both activities are simulated for the same modelling year, but the combination of both is assured by the fixed relation of 0.0:1 to 0.5:1.

Table 19: Conservational Tillage Shares in the EU-15

Country	CVT*	No-Till	Country	CVT*	No-Till
	(% of arable land)			(% of arable land)	
Belgium	10.0	0.0	Denmark	8.0	0.0
Ireland	4.0	0.3	United Kingdom	30.0	1.0
France	17.0	0.3	Spain	14.0	2.0
Germany	20.0	3.0	Italy	6.0	1.0
Portugal	1.3	0.8			

**CVT: conservation tillage (in this study: no-till and mulch seeding).*
Source: ECAF (2007).

3.3.3.2 Yields

Although nowadays it is common knowledge, it was only in the 19th century that the importance of soil fertility to a farm's total revenue was first described by scientists like THÜNEN (1966). In these days, THAER (1809), who is remembered as a founder of independent agricultural sciences, analysed rotational field management, popular in Great Britain during that epoch. He stated that it should not be the goal of a farmer to produce maximal yield, but to achieve maximal gains. Some decades later, agricultural production experienced a great step forward with the introduction of mineral fertilisers like the water soluble phosphate fertilisers (super phosphate) developed by Justus von Liebig.

The discovery of the above described linkages between agricultural output on one hand, and natural conditions, field management, and fertiliser input on the other, was decisive for the furthering of higher yields, and hence the nutrition of a growing population. The simulation of this multi-dependency represents a challenge to agricultural modelling. Site-specific functions that give expression to the link between nutrient input and yield development under a set of site-specific conditions are pursued.

3.3.3.2.1 Yield Function

In economics in general, the preference is for production functions that are founded on neoclassical theory and express output as dependent on factor input(s). These neoclassical production functions feature sections of changing marginal incremental output, i.e. sections with disproportionately low or high marginal incremental output. High increments are typically in the function's first section, gradually changing to low increments. Of relevance to the determination of economic optima are only those sectors of decreasing marginal outputs.

In agriculture, quadratic functions, a sub-type of neoclassical production functions featuring a hyperbolic form, are prominent for the depiction of yield, since even negatively sloping yield developments can be described. That is also the main asset in comparison to alternative yield functions that may achieve a similar or even higher coefficient of determination, like Mitscherlich-functions (MITSCHERLICH, 1909), but cannot depict the negative yield effect of (exuberant) factor input beyond maximum yield. An example of this type of yield effect is super-fertilisation causing burns to plant leaves, and finally affecting yield negatively.

Quadratic yield functions, under ceteris paribus assumptions, are well tested for the depiction of agricultural yields dependent on nutrient input. However, their integration into a linear programming model is aggravated. The precondition for any linear programming model of constant input-output-relations cannot be fulfilled by a quadratic function with continuously changing slopes. The solution is the depiction of the input-output-relation in discrete steps. Without losing too much information the quadratic function is linearly approximated for certain points of the original curve.

The default form of a quadratic yield function and its coefficients can be determined econometrically by drawing back on results from field experiments. KRAYL (1993) performed a regression analysis on results obtained from numerous progressive nitrogen fertilisation experiments across Central Europe for different field crops. Naturally, these experiments are only valid for the specific site of the experiment and its specific conditions. By standardising the (quantitative) maximum yields and respective nitrogen inputs these functions were converted to site-unspecific but crop-specific yield functions. The default form of this so-called relative yield function can be read in the following formula (BAUDOUX, 2000):

Formula 5: Relative Quadratic Yield Function in Single Factorial Case

$$\boldsymbol{Y_{rel} = aN_{rel}^{\,2} + bN_{rel} + c}$$

with:

Y_{rel}	relative yield
N_{rel}	relative nitrogen fertilisation
a, b, c	coefficients of the relative yield function

The absolute yield function is derived by applying site-specific maxima yield and respective nitrogen inputs to this (site-unspecific) relative yield function. Since both values are unknown for the entity of agricultural fields, KAZENWADEL (1999) based his procedure on the known relation between yield and profit:

Formula 6: Crop Profit in the Single Factorial Case

$$\boldsymbol{P}(\boldsymbol{N}) = \boldsymbol{Y_{abs}} \times \boldsymbol{p_p} - \boldsymbol{N_{abs}} \times \boldsymbol{p_N} - \text{fixedcosts}$$

with:

Y_{abs}	absolute yield
p_p	sales price for crop product
N_{abs}	absolute Nitrogen input
p_N	purchase price for Nitrogen fertiliser
fixedcosts	fixed costs

By replacing Y_{abs} with Formula 5 and by differentiating the profit function, Kazenwadel calculated the optimal special intensity and he could prove by a number of transformations where, under known crop sales price and nitrogen purchase price, the optimal yield and the corresponding nitrogen input suffice to deduce the absolute yield function. Optimal yield herein is used in the sense of economically optimal.

One central premise of neoclassical production theory is the concept of the *homo economicus,* an individual that acts rationally to obtain the highest possible well-being given available information about opportunities and other constraints. While other factors of well-being like leisure are satisfied at a minimal level, an entrepreneur aims at maximizing gains (STEINHAUSER et al., 1992, p.72). This means that measured respective surveyed yields corresponded to economically optimal yields (if production conditions like weather were known a priori by producers), the first relevant size for the deduction of the above absolute yield function. The corresponding nitrogen input, the second relevant size, is oriented by the total nutrient withdrawal for the optimal yield including plant by-products (straw, stalks, etc.), and other residues (like roots). Default factors for withdrawal rates per unit of yield, as shown in Table 20, are applied.

Table 20: Nitrogen Withdrawal by Plants

Crop	**Grain**	**By-product**	**Crop**	**Grain**	**By-product**
	(kg/dt)			(kg/dt)	
wheat	2.10	0.50	rapeseed	3.30	0.70
winter barley	1.70	0.50	sunflower	2.80	0.50
summer barley	1.70	0.50	sugar beet	0.18	0.30
oats	1.60	0.50	potato	0.35	0.40
rye	1.60	0.50	silage maize	0.36	0.36
grain maize	1.40	0.70	clover	0.52	0.52
soy bean	4.40	1.50	catch crop	0.50	0.50

Source: BUNDESGESETZBLATT *(2006).*

To summarise, via surveyed local yields the absolute site-specific yield function can be deduced. In EU-EFEM, the applied yield function expresses a one-factorial case, yield in dependency of nitrogen. The other macro- and micro-nutrients considered in EU-EFEM (P_2O_5, K_2O, Mg, and Ca) are only estimated in correspondence with default nutrient withdrawals (see Annex 1) for considered yield levels; this means that no site-specific conditions change the input-output-relation for the same coefficients like for nitrogen.

3.3.3.2.2 Yields for Management Alternatives

Predicting yields via yield functions as described above required empirical data (from field experiments). This empiric data was only from crops under conventional tillage and with a standard management of plant residues. For conservational tillage and alternative straw treatment such empirical data is not available. In conventional tillage the straw treatment does not matter too much with respect to yields if a plough is used, since the negative effect from increased pest pressure from pathogens on residues or from inhibited germination can be widely dampened.

Because of the missing empiric data on conservational tillage, and on conservational tillage in combination with different management of plant residues, alternative data is necessary. Within the network of INSEA, where EU-EFEM also participated, the biophysical EPIC model can serve as a data source instead. EPIC yield simulations were available for conventional and conservational tillage and for all straw including if no straw was left for field decay. The regional resolution of this data is on HRU level, which is below the regional level of EU-EFEM.

The yield functions used for crops under conventional tillage feature site-specific validity and show the advantage of constructing a link between site conditions, fertilisation and yield. This link is not constructed by EPIC, so that for conventionally tilled crops, the yield simulated by EU-EFEM remained based on the yield functions. Otherwise it would have been necessary to do simulations for all discrete steps of fertilisation intensity simulated in EU-EFEM. Using nevertheless the alternative EPIC data for the crops under conservational tillage, the same link between fertilisation and yield from crops under conventional tillage had to be assumed[38]. That is the reason why only the difference in yield in relation to conventional tillage is considered[39].

That means that from EPIC five simulations were taken: 1 conventional tillage, 2 tillage alternatives, and 2 plant residue alternatives. The two alternative managements of plant residues represent extreme cases. Between both extremes a linear relation was assumed. In EU-EFEM this linear relation is depicted by 6 discrete steps. Combining these discrete steps with the two optional tillage schemes (mulch seeding and no-till) the following plant production alternative can be simulated by EU-EFEM (in addition to conventional tillage):

1. Mulch seeding with 0%, 20%, 40%, 60%, 80% and 100% of above-ground plant residues left on field for decay.
2. No-till with 0%, 20%, 40%, 60%, 80% and 100% of above-ground plant residues left on field for decay.

In order to give an idea of the impact of the tillage and the residue management on yields a comparison to conventional tillage with normal treatment of residues is appended. The values are averaged over all HRUs representing the EU-15. Thus these values are to be handled with precaution since they are not weighted according to the area represented by each HRU. Further averaging over HRUs is problematic since all kinds of site conditions and rotational effects from preceding crops implied by the HRUs are haphazardly combined.

---

[38] This means that a changed nutrient availability from soils under conservational tillage is not accounted for.

[39] EPIC simulations are rotation and site specific (summarised in the HRUs; compare section 3.2). Here, an average value over all rotations of the respective crop was deemed sufficient. Otherwise the modelling expense would have been much larger.

Table 21: Change of Yield in Comparison to Conventional Tillage (Averaged over HRUs)

	Mulch Seeding		No-Till	
Crop	**0% Straw**	**100% Straw**	**0% Straw**	**100% Straw**
	(%)		(%)	
grain maize	-1.6	-3.9	-7.0	-11.4
barley	-0.8	-1.9	-3.2	-5.1
rape	-2.2	-4.0	-4.1	-6.2
rye	-4.2	-7.9	-6.4	-11.9
winter wheat	-1.5	-1.9	-4.6	-5.4
oats	-0.9	-3.0	-3.0	-5.7
potato	-2.1	-4.3	-8.5	-14.0
sugar beet	-3.4	-7.1	-9.7	-16.8
sunflower	-5.4	-9.5	-8.5	-15.3
silage maize	-0.5	-1.2	-4.7	-7.2
field pea	-5.0	-5.0	-4.1	-3.9
green clover	-0.5	-1.5	-0.3	-2.1

Source: Own calculation based on EPIC simulations by Schmid (2007)

3.3.3.2.3 Crops of Arable Land

In EU-EFEM the simulated crops of arable land exclude permanent crops, but include the main cash crops in the EU: (1) silage maize, (2) grain maize, (3) rice, (4) soy bean, (5) wheat (winter and spring), (6) barley (winter and spring), (7) oats, (8) rye, (9) rapeseed, (10) sunflower, (11) potatoes, (12) sugar beet, (13) pulses (field peas), (14) green clover, (15) catch crops, and (16) fallow land normally grown with mustard.

For each of these crops 15 intensity levels are formulated, each one defined by a certain amount of fertiliser input. From one level to the next a stepwise increase by 20 kg nitrogen is assumed, meaning a range from 0 to 300 kg is covered. Only for winter catch crops only one intensity level with zero fertilisation is formulated. This is because the purpose of catch crops is to accumulate nitrogen and/or to protect soil from erosion and it is not to produce maximal yield. Technically speaking, the simulation of intensity in classes, i.e. in discrete steps, represents a linear approximation to the (hyperbolic) yield function.

3.3.3.2.4 Grassland

The simulation of grassland production follows the simulation of crop production on arable land. Due to the lack of publications about grassland yields spanning the entire EU, the deduction of a site-specific yield function, where the absolute yield function is available, was more difficult. Although grassland has been paid scant scientific attention during recent decades, its importance to this study should not be underestimated. Grassland for animal feeding, biomass to bio-energy, and for the accumulation of soil organic matter are decisive aspects to this study.

Experimental grassland yields (e.g. MLR, 2005) in the original EFEM-version were only for Baden-Württemberg. In the original version these yields were specified according to the number of yearly cuts (ceteris paribus all other regional parameters) and modified by assuming average loss rates of organic matter per conservation procedure. The loss rates were 10% if used as green fodder, 15% in grazing systems, 15% if harvested as silage, and 20% if harvested as hay.

The widened regional scope of EU-EFEM, however, requires EU-wide (EU-15) grassland yields, and the values from the Baden-Württemberg trials are insufficient. Assuming fertilisation, yearly rainfall, and temperature sum as the main drivers for the development of grassland plant stands, the values of the original EFEM (Table 22) could be modified according to these drivers, and were fitted to the expanded EU-EFEM. Since one of the drivers (fertilisation) is not statistically surveyed, the modifications could only be orientated by the statistical rainfall and temperature data.

Table 22: EU-EFEM's Gross Yields of Grassland and Linked Nitrogen Demand

	1 cut	**2 cuts**	**3 cuts**	**4 cuts**	**5 cuts**
Gross yield (t FM/ha)	17.85	29.75	36.12	40.80	43.35
Nitrogen demand (kg/ha)	26.86	63.30	98.83	148.84	191.08

Source: Own estimate based on values from older EFEM versions (for example, ANGENENDT, 2003).

In terms of rainfall and temperature, the sum of the yearly rainfall and yearly mean temperatures are not the only important variable, but also their yearly distribution. According to the author's own assumed relations between rainfall, mean temperatures, and yearly distribution of rainfall, the original yield data was modified. For the modified yield the nutrient demand was subsequently calculated following the procedure for arable crops.

3.3.3.3 Plant Nutrients

In plant production the main nutrients with respect to plant growth are nitrogen, phosphate and potash. As concerns micro nutrients, magnesium and calcium are simulated. Nutrient input (fertilisation) is from natural or anthropogenic sources.

Although this context is simple, the quantification of nutrient availability to plants is complex due to the number of natural sources and their mutual interaction. The interaction is dynamic and takes the form of freeing and storage mechanisms. The motivation for the proper simulation of such nutrient cycling is twofold since the economies of plant production (yields and fertiliser expenditures) and the environment are affected. Environmental threats fall together with catch phrases like groundwater pollution or eutrophication.

Dominant beyond doubt as regards the aforementioned aspects is nitrogen. In addition to manmade fertilisation, like also for all other nutrients, steering parameters of natural nitrogen cycling are represented by soil processes, rainfall, and biological fixation. Under soil processes fall the mobilisation and immobilisation of soil organic matter to plant available nitrate. Soil organic matter constitutes the soil's nitrogen stock and is influenced by plant uptake, nitrogen return from organic matter input (organic fertilisation or plant residues), and leaching (see section 2.1.1).

The first version of EFEM quantified mineralisation and leaching via functions. The deduction of the functions was by regression analyses conducted by KRAYL (1993) on model results from a biophysical model (FELDSIM). He expressed N-leaching in proportion to the plant available nitrogen stock on level of the EFEM production periods (see 3.3.3) (the approximations for the single periods can be found in KRAYL (1993)). Their validity was at average conditions of the then study region, Baden-Württemberg, which has average temperatures between +6.0°C and +9.5°C, average precipitation from 500 - 990 mm, soil humus contents from 0.8 - 3.6%, and topsoil depths from 10 - 30 cm. This limited validity does not suffice to reflect the scope of EU-EFEM, with mean temperatures from -2.0°C to +17.0°C and annual precipitation levels from 460 - 1600 mm.

Alternatively, mineralisation among the main processes in nutrient cycling could be integrated from biophysical simulations realised within EPIC[40]. From EPIC the yearly mineralisation value was copied. EPIC simulations according to EU-EFEM modelling periods were not available, but the modelling periods form an integral part of EU-EFEM. In order to not completely lose the information in Krayl's periodical approximations, the yearly mineralisation value from EPIC was distributed to the EU-EFEM periods according to the original distribution of the EFEM's yearly

---

[40] EPIC simulations were available on a NUTS-II level.

mineralisation. For leakage, also among the main processes in nutrient cycling, the same procedure was adopted.

3.3.3.3.1 Organic Fertilisation

In EU-EFEM, crops' nitrogen requirements are satisfied from two sources: 1) mineral fertilisation, and 2) the nitrogen soil pool. The discrimination of the two sources against each other is substantiated by the different temporal availabilities. In mineral fertilisation plant availability is fast and often immediate, while nitrogen from the soil pool is subject to mobilisation from formerly immobilised nitrogen, often from organic fertiliser, and which is a gradual process. The speed of the latter depends on the soil activity, influenced by temperature, moisture, C/N-ratio, and so on. The simplified nitrogen cycle from Figure 2 illustrated the linkage between nitrogen movements and initial nitrogen stock, which are subject to organic matter input, mobilisation and immobilisation, processes which will be described in the following.

KRAYL (1993) and KAZENWADEL (1999) elaborated a simulation tool to integrate this dynamic nitrogen cycling into the yearly and linear EFEM. Formula 7 shows the equation used and the main variables (variables in bold italics) as simulated in EU-EFEM. The equation controls the total (yearly) nitrogen soil pool via the variable "soilpool" which increases and decreases according to the sum of nitrogen inputs minus total mineralisation.

Formula 7: Total Nitrogen Soil Pool (in kg/ha)

$$
\begin{aligned}
0 = & \sum_{crop} \left[\mathrm{rootN(crop)} \times \boldsymbol{area(crop)} \right] \\
& + \sum_{ani,manu,per} \left[\mathrm{unavlfert(ani, manu, per)} \times \boldsymbol{manure(ani, manu, per)} \right] \\
& + \sum_{crop,per} \left[\left(\mathrm{CNbalance(crop, per)} + \mathrm{unavlresid(crop, per)} \right) \times \boldsymbol{litter(crop)} \right] \\
& - \mathrm{totmineral} \times \sum_{crop} \left[\boldsymbol{area(crop)} \right] \\
& - \boldsymbol{soilpool}
\end{aligned}
$$

with the indexes:

crop	crop
ani	animal category
manu	manure type (liquid or solid)
per	EU-EFEM model period

the parameters:

rootN(crop)	N in residual roots (kg/ha)
unavlfert(ani,manu,per)	unavailable N from organic fertilisers (kg/m^3)
CNbalance(crop,per)	N needed to balance C/N-ratio (kg/dt)
unavlresid(crop,per)	unavailable N from plant residues (kg/dt)
totmineral	total yearly N mineralisation (kg/ha)

and the positive variables:

area(crop)	crop area (ha)
manure(ani,manu,per)	periodic organic fertilization (m^3/ha)
litter(crop)	litter left on field (dt/ha)

and the free variable[41]:

soilpool	Δ-Nitrogen soil pool (kg/ha)

The periodicity of EU-EFEM is also reflected in the simulation of the nitrogen pool. In contrast to Formula 7, which controls the total yearly nitrogen pool, Formula 8 controls the periodic nitrogen pool. Periodic nitrogen pool means that leaching, N-transfer from previous periods, organic fertilisation and other variables are modelled on basis of EU-EFEM modelling periods. Thereby the variable 'withdrawal'[42] satisfies the plants' nitrogen need.

Formula 8: Periodic Nitrogen Soil Pool

$$\begin{aligned} 0 = {} & \boldsymbol{\mathit{withdrawal(per)}} + \boldsymbol{\mathit{nstore(per)}} \\ & - \sum_{\mathrm{per}-1}\left[\boldsymbol{\mathit{nstore(per-1)}} \times \mathrm{leaching(per)}\right] - \sum_{\mathrm{crop}}\left[\left(\mathrm{permineral(per)} + \mathrm{atmdepos(per)}\right) \times \boldsymbol{\mathit{area(crop)}}\right] \\ & - \sum_{\mathrm{ani,\,manu}}\left[\boldsymbol{\mathit{manure(ani,manu,per)}} \times \mathrm{availfert(ani,manu,per)}\right] \\ & - \sum_{\mathrm{crop}}\left[\boldsymbol{\mathit{litter(crop)}} \times \mathrm{availresid(crop,per)}\right] \\ & - \boldsymbol{\mathit{soilpool}} \times \mathrm{avmineralisation(per)} \end{aligned}$$

with the parameters:

leaching(per)	N leaching (kg/ha),
permineral(per)	N mineralisation (kg/ha),
atmdepos(per)	atmospheric deposition (kg/ha),
availfert(ani,manu,per)	available N from organic fertilisers (kg/m^3)
availresid(crop,per)	available N from plant residues (kg/dt)
avmineralisation(per)	long-term average mineralisation of soil pool (kg/ha)

---

[41] It can assume positive and negative values.

[42] Although this variable is on a periodic basis, the nitrogen need is formulated on a yearly basis. A more detailed simulation of nitrogen need would be beyond the scope of the model.

and the variables:

withdrawal(per)	N for plant growth (kg/ha)
nstore(per)	nitrogen immobilisation (kg/ha)
area(crop)	area per crop (ha)
manure(ani,manu,per)	organic fertilisation (m3/ha)
litter(crop)	litter left on field (dt/ha)
soilpool	Δ-Nitrogen soil pool (kg/ha)

The satisfaction of the nitrogen need by accounting for periodic provision from natural sources (nitrogen pool, deposition, etc.) and organic fertilisation has just been described. In contrast and in addition to the down sloping yield beyond the point of maximal yield on the quadratic yield function, slurry and manure are additionally controlled by upper limits. Sprouting or cauterised plant material is caused by exuberant organic manure application (Hoffmann and Hege, 1991; Ruppert et al., 1985). On arable land, the set limits are periodic and crop specific, since each crop reacts with a different degree of sensibility to super-fertilisation. For grassland, upper limits orientate by the number of cuts. Table 23 shows the maximum application quantities of slurry in crops according to modelled periods. For solid manure similar restrictions are integrated into the model.

Table 23: Maximum Allowed Application of Slurry

Crop	**Mar**	**Apr-Jul**	**Aug**	**Sep-Oct**	**Nov-Feb**	**Year**
	(m^3/ha)					
winter cereals	25	20	0	0	10	40
summer barley	0	0	0	0	0	0
other summer cereals	20	25	0	0	0	30
maize	20	60	0	0	0	60
rapeseed	30	0	20	0	10	50
sunflower	15	15	0	0	0	20
potatoes and beets	30	20	0	0	0	30
catch crop	0	0	30	0	0	30
green clover	30	40	20	0	0	40
grassland, 1 cut	25	15	0	0	0	25
grassland, 2 cuts	25	15	10	0	0	50
grassland, 3 cuts	25	35	10	5	0	75
grassland, 4 cuts	25	45	10	20	0	100
grassland, 5 cuts	25	55	20	25	0	110

Source: Ruppert *et al. (1985);* Hoffmann *and* Hege *(1991)*

3.3.3.3.2 Mineral Fertilisation

In the previous section it was mentioned that mineral fertilisers are not accounted for in the simulation of the nitrogen pool because the nitrogen in them is usually quick and often immediately available to plants and thus does not take the detour through the nitrogen pool. The relation between quicker and slower nitrogen in mineral fertilisers depends on the type of fertilizer. Since each type shows specific characteristics, in this section the fertilizer types simulated in EU-EFEM and their characteristics will be shortly explained.

In EU-EFEM mineral fertilisers are defined by the contents of main plant nutrients (nitrogen, phosphate, potash, magnesium and calcium; sulphur is not considered). Exclusively nitrogen fertilisers are further split into “urea” (containing amid group) and “non-urea” fertilisers. This split is due to different potential environmental harms of both (section 3.3.5, “Ammonia Emissions”) and different purchase prices. The group “non-urea” comprises of the most common nitrogen fertilisers in the EU-15. According to the European Fertilizer Manufacturers Association’s database these are (EFMA, 2005): ammonium nitrate, ammonium phosphate, ammonium sulphate, calcium ammonium nitrate, nitrogen solution (urea ammonium nitrate), and nitric acid.

3.3.4 Bio-Energy Production (Biogas)

Apart from traditional agricultural products, EU-EFEM also simulates agricultural bio-energy production. In this respect the sole focus is on biogas while additional agricultural bio-energy products are disregarded. It was consented with the simulation of biogas production, because other products like of bio-ethanol or biodiesel have already been simulated in comparable programming models and because biogas production is special due to the refining of potential wastes or low value (intermediary) products like grass or manure. There are a number of studies simulating bio-energy production in programming models. The interested reader might, for example, refer to TRIEBE (2007). He simulated the production of bio-ethanol and biodiesel in a linear programming model constraining the model by formulating a maximum share of arable land available to bio-energy production. Thereby, the general disadvantage of programming models, which is the overspecialisation, has been partially avoided. However, although justified by secondary literature, the formulated maximum share of arable land is not qualified by a market model.

3.3.4.1 Structure in the Simulation of Bio-Gas Production

The simulation of biogas production in EU-EFEM is rather detailed in comparison to comparable models. For example, a quite extensive selection of agricultural substrates can be utilized and be combined with considerable flexibility. Further, the size of the biogas fermenter is not predefined. In contrast, the remuneration of produced bio-energy is described in a rather simple way. The diverse legislation with respect to remuneration or investment incentives in the EU-15 favoured this procedure. Moreover, in some countries prevailing legislation mandates minimum national quotas for biogas. The purpose of this modelling exercise, which is the simulation of the market potential of biogas production, would thus have been untenable.

The German remuneration rates are laid down uniformly to all modelled regions. The German system is based on guaranteed prices stipulated by the Renewable Energy Act (German: Erneuerbare Energien Gesetz, EEG). In the version from August 1, 2004, a base rate plus eventual bonuses is described (VDN, 2003). The bonuses are eligible in the event of the sole fermentation of renewable resources, the recovery of thermal energy, and the application of latest advanced technology. A similar system is only in place in Spain.

The biogas plants simulated in EU-EFEM are either of the type mono-fermentative (only slurry) or co-fermentative (slurry and co-substrates). The fermentation process is implemented as single-stage fermentation (representing common practice standard) under mesophile and wet conditions. Mesophile conditions prevail if the bacteria are comforted with temperatures around 38°C. By recycling process energy and driving it back to the fermenter (to the necessary extent) mesophile conditions are established efficiently. Wet conditions are interpreted as conditions with total dry matter content below 20%[43] in the substrate. The substrate mixture still remains pumpable at this level (pumpable mixtures have a DM-content below 16%, see section 2.3.2), provided that a certain share of digested effluent is driven back to the fermenter. The legal organisation of the biogas plant is in individual ownership or in a co-operative for larger plants. In both cases the substrate supplier receives the proportionate share of digested effluent for fertilisation purposes.

---

[43] Although only a DM content of up to 16 % is possible in wet fermenters, it is assumed some fermented liquid substrate was driven back to vaccine the newly fed-in substrates.

For the extraordinarily high investment costs and the long-term character of the investment, fixed costs are integrated into the model. This is against the normal procedure in EU-EFEM which maximises gross-margins. Integrating fixed costs helps to control the extent of biogas production, which in the absence of fixed costs, would be overestimated by far[44]. In EU-EFEM fixed costs of biogas production are reflected by a binary decision variable which makes that farmers can opt for one out of three plant sizes for which fixed costs were predefined. Therein plants sizes are defined by the electric capacity of the CHP unit and by minimum and maximum fermenter volume.

Notwithstanding the restriction to three predefined plant sizes (CHP capacity and fermenter volumes), the simulation of biogas production is rather flexible, while at the same time accurate. This balancing act is achieved by predefining fixed costs only for the CHP unit and the minimum fermenter volume. The minimum fermenter volume obeys the biological and at the same time economic restriction of the biogas process reflected in optimal retention times for biogas substrates. Recommended retention times are 44 days for maize (copied for other crops), 32 days for cattle slurry, 25 days for pig slurry, and 32 days for poultry slurry (AMON and DÖHLER, 2006). The overall retention time of the substrate mixture represents the weighted average.

The minimum fermenter volume per size class is for maize as single substrate since maize is most effective per unit of fermenter volume; i.e. it shows the narrowest relation between retention time and dry matter content, the main determinant for biogas development. However, since this mono-fermentation of maize does never satisfy the constraint of a pumpable substrate mixture it is only an “unproductive minimum volume”.

Vice versa, the maximum fermenter volume is for the substrate with the widest relation between retention time and dry matter content. This applies to cattle slurry. In contrast to the before the mono-fermentation of cattle slurry is practicable. Thus the calculated maximum volume represents a “productive maximum volume”. An idea of

---

[44] An argument against the integration of fixed costs normally is that certain production factors are available on farms anyway. This is true for production factors that can be used for a number of production activities, like a plough for wheat and for barley. In biogas production however, a rather new branch of production, few capacities were already available across Europe in the reference year 2003.

the range between minimum and maximum fermenter volume can be gained from Table 24 for the three eligible CHP size classes of 150 kW_{el}, 250 kW_{el}, or 600 kW_{el}.

Table 24: Fermenter Volumes acc. to the Biogas Plant's Size Class

	kW 150	**kW 250**	**kW 600**
		(m^3)	
minimal volume (unproductive)	407	643	1,669
maximal volume (productive)	2,313	3,652	9,488

In EU-EFEM, a binary decision variable controls that maximally one out of the three size classes is selected. A second variable constrains the maximum fermenter volume for the selected size class. With respect to fixed costs, the first binary variable forces the fixed costs of the correspondent plant size involving the costs for the CHP plant plus the minimum (unproductive) fermenter volume. The fixed costs of any further unit of fermenter volume are internalised via a second variable that converts the fixed costs per additional unit of fermenter volume (incl. upstream and downstream costs in the production chain) into quasi-variable costs. Quasi-variable costs because the activity level of the variable can be changed every production period[45], an assumption that does not reflect reality: a once constructed fermenter cannot be modified annually in its size. The cost coefficient of the variable is for investment costs linked to the additional fermenter volume needed per type of substrate and is thus indexed with the type of substrate.

All cost items including fixed costs were annualised in order to fit into the annual structure of EU-EFEM. The investment costs are annualised via the theoretical parameter "annual depreciation". Linear depreciation up to a remaining value of zero is assumed (it calculates as the investment cost minus remaining value divided by the lifespan in years). The assumed lifetimes are shown in the following section below.

For each fermenter, the specific process heat demand to achieve the objective temperature of 38°C is calculated as a function of ambience and substrate temperatures at fermenter filling. It is composed of the heat necessary to warm up the substrates and of the heat compensating heat losses by the fermenter, like applied by Scholwin (SCHOLWIN, 2006, p.20). He approximates the first by the

---

[45] This represents a simplification within the annual static EU-EFEM. To the general problem of simulating fixed costs in such a kind of model, where single production periods are solved independently from one another, no solution is given herewith.

warming capacity of water and deduces the second from the so-called heat transition coefficient per surface area (so-called “k-value”), expressing the quality of insulation and the surface area. Apart from at the fermenters’ outer skin, heat losses occur at the inlets for mixers or for the feeding unit. In this study, they are assumed to be in the dimension of 15% of the accruing thermal energy and the fermenter heating is assumed to have an efficiency rate of 85%. In Table 25, the assumed values and resulting process energy needs are indicated.

The generators of the CHP units with kW 150 and kW 250 are driven by pilot injection engines, while in the kW 600 unit a Gas-Otto engine combusts the biogas (compare Table 25). Pilot injection engines make sense in smaller plants because of lower relative investment, and these engines are available on the market only up to 250 kW_{el} (SCHOLWIN, 2006, p. 103, Table 5 - 7). These engines are run on 10% ignition oil in relation to the total heating value of combusted biogas. At higher shares of ignition oil the renewable resource bonus would be rejected according to the German Renewable Energy Sources Law (VDN, 2003), at lower shares proper functioning would be endangered.

3.3.4.2 Cost and Lifetime Aspects of Bio-Gas Equipment

The ***engine***’s lifespan (in years) is the total operating hours divided by the yearly runtime. The total operating hours are indicated with 35,000 h for pilot injection engines and 60,000 h for Gas-Otto engines (SCHOLWIN et al., 2006, pp.102 - 103). A yearly runtime of 8,000 h is assumed, leaving 760 h for repair and maintenance. Longer down times should be rigidly avoided (JÄGER et al., 2006, p.168). Thus the lifespan is around 3.4 years for pilot injection engines and 7.5 years for Gas-Otto engines. The investment costs can be approximated with 385 (kW 150) to 500 €/kW_{el} (kW 250) for pilot injection motors and 560 €/kW_{el} (kW 600) for Gas-Otto engines (compare SCHOLWIN et al., 2006, p.109). The total investment cost divided by the lifespan thus gives a yearly depreciation of approx. 13,000, 29,000, and 45,000 € for the considered engines. The additional running costs expressing in the yearly repairs and maintenance costs are from 1.8 ct/kW_{el} in complete service contracts (SCHOLWIN et al., 2006, p.109) to 0.4 ct/kW_{el} in own execution (SCHÄFER, 2006, p.143).

For other ***technical equipment*** (CHP, mixing and feed-in unit) a lifespan of 10 years is assumed. The investment is from 880 (kW 150) to 620 €/kW_{el} (kW 600), giving a yearly depreciation between 88 and 62 €/kW$_{el}$. For simplification reasons, it is assumed the technology sufficient for the entire range of fermenter volumes falling in between the minimal and maximal volumes per plant size class. The yearly repair costs hold as 3% of the investment cost.

For the ***constructions*** (fermenter and buildings), a lifespan of 20 years is assumed. The investment costs for the fermenter and other buildings total between 1100 (kW 150) and 750 €/kW$_{el}$ (kW 600). Dividing these costs by 20 years, a yearly depreciation between 55.0 and 37.5 €/kW$_{el}$ is obtained. With respect to the fermenter, these rates only valid as to the minimum fermenter volume. Any additional volume unit is available at annualised costs of 100 €/m^3. For all constructions, yearly repair costs approximately hold as 1% of the investment.

Similarly to manure, effluent from biogas plants has to be stored at least during the winter season. It is assumed that for manure being treated in biogas plants, storage facilities are already available, since no additional manure is produced because of a biogas plant. In contrast, biogas plants drawing on crop substrates are assumed to require additional ***storage facilities***. Also large biogas plants of kW 600 require additional storage facilities, since such a large production capacity will probably not originate from only one farm and so storage facilities have to be constructed near to the biogas plant. Investment costs into storage facilities are 50 €/m^3. The lifespan is 25 years, which gives a yearly depreciation of 2 €/m^3.

Other costs are for the insurance of the plant and the interest on capital. On average, insurance claims 0.5% of the investment in constructions, technology, and engines. As the time of investment becomes more distant past, the interest on capital decreases proportionately. At the same time repair costs raise. Both movements balance over the machinery's and technology's lifetime. Therefore the interest on capital can be approximated by cost-value minus remaining value divided by two (REISCH and ZEDDIES, 1992, pp.70 - 71). The interest rate is assumed as 6%.

Biogas production also requires ***labour*** input for maintenance and control works but in the case of plant substrates for substrate feeding too. Labour costs are estimated at a national level. For Germany 15 € is assumed while other countries the range is from 8 € (Greece) to 17 € (Denmark, Finland, and Sweden). It is assumed all work at the plant itself is done by non-family members at the above salary, while the preparation of substrates, for example, is done by family members, which means it is cost free, if capacities are available.

In case of pilot injection engines ***ignition oil*** is necessary. Its price corresponds to the price of heating oil. This study applied the national average price of the years 2005 to 2007 of heating oil for private households taken from EUROSTAT (2007b).

The ***remuneration of electricity,*** as mentioned in the beginning, is according to the rates of the German EEG of 2004. Matthias and associates (MATTHIAS et al., 2006, p.138) indicated the base rate with 11.5 (plants from 0 - 150 kW_{el}), 9.9 (plants from 150 - 500 kW_{el}), and 8.9 ct/kWh_{el} (plants from 500 - 5,000 kW_{el}). The exclusive fermentation of renewable biomass including animal excreta was rewarded 6 (plants from 0 - 500 kW_{el}) or 4 ct/kW_{el} (plants from 500 - 5,000 kW_{el}). Electricity production in CHP units with partial heat recovery was rewarded an additional 2 ct/kWh_{el} (plants from 0 - 20,000 kW_{el}). The technology bonus of 2 ct/kWh_{el} (plants from 0 - 5,000 kW_{el}) was granted if new technologies like fuel cells or gas turbines were applied. All these rates have experienced an annual decrease by 1.5% since January 1, 2005. This decrease is also reflected in EU-EFEM, where prices on the level of 2007 are integrated.

The ***remuneration of waste heat***, if sold, is according to the substitutive value[46] orientated by the price of heating oil and diminished by 10 ct/l for infrastructure and miscellaneous costs.

3.3.4.3 Cornerstones of Biogas Production Reflected at Imaginary Plants

For three imaginary biogas plants, reflecting the three basic CHP size classes, the main parameters of production and profitability are illustrated in Table 25. It is assumed each of the three imaginary plants would produce at its capacity limit of installed electric performance and all would use the same substrate mixture. The mixture consists of maize (40%), pig slurry (18%) and cattle slurry (42%) (percentage on weight basis). The mixture has a dry matter content of 15.8% and thus is pumpable. The revenues are for the case that all electricity and 30% of waste heat are sold. Heat is remunerated with its substitutive value of 38 ct/l (heating oil). In the cost calculation 48 ct€/l of ignition oil 8 ct€/kWh of process electricity are assumed.

---

[46] The equivalent energy value of biogas assumed: 1 kWh biogas substitutes 0.1 l heating oil.

Table 25: Coefficients of Imaginary Biogas Plants

	Unit	kW 150	kW 250	kW 600
Properties				
total investment	(1000 €)	465	698	1,608
produced gross energy	(MWh/a)	3,318	5,239	12,250
silage maize (fresh weight)	(t)	1,156	1,826	4,743
cattle slurry	(t)	9,487	14,979	38,916
pig slurry	(t)	4,526	7,146	18,565
Gas Utilisation				
engine type		Pilot Injection		Gas-Otto
electric efficiency	(%)	33	35	38
thermal efficiency	(%)	38	39	43
Gas Development				
k-value	(W/°C/m^2)	0.36	0.32	0.26
fermenter volume (gross)	(m^3)	1,496	2,363	6,138
accruing electric energy	(MWh/a)	1,095	1,834	4,655
electric process energy	(MWh/a)	44	73	186
accruing thermal energy	(MWh/a)	1,261	2,043	5,268
thermal process energy	(MWh/a)	790	1,196	2,683
Economics				
Annualised Investment and Maintenance Cost				
constructions and technology	(€/a)	26,994	37,636	82,134
engine	(€/a)	13,200	28,629	44,880
storage	(€/a)	1,481	2,339	56,372
interest on capital (6%)	(€/a)	13,955	20,939	48,254
insurance (0.5%)	(€/a)	2,326	3,490	8,042
repair constructions (1%)	(€/a)	2,750	3,927	9,011
repair technology (3%)	(€/a)	3,974	5,400	11,124
repair engine (0.8 ct/kWh_{el})	(€/a)	8,760	14,672	37,240
Other Annual Cost				
production costs of maize[47]	(€/a)	20,546	32,454	84,299
electricity bought	(€/a)	5,037	8,436	21,413
ignition oil	(€/a)	15,926	25,147	--
imaginary salary	(€/a)	5,665	8,946	23,240
Revenues and Profit				
electricity sold	(1000 €/a)	208	337	815
heat sold (30% of available)	(1000 €/a)	16	29	88
Profit Calculation				
Total Annual Costs	(1000 €/a)	120	192	427
Total Annual Revenues	(1000 €/a)	224	366	903
Profit	**(1000 €/a)**	**104**	**174**	**477**

The table is meant to give only a rough idea of the simulation of biogas production in EU-EFEM. Region specific production costs of a medium costs region were involved to be able to calculate profitability. The East German region of

---

[47] In accordance with the approach presented for the calculation of plant production costs, fertilizer expenditures are not included.

“Brandenburg-Nord” was chosen. There, production cost of maize are 533.20 €/ha or 17.80 €/t (based on the average regional yield). The process heat demand is for the local average ambient temperature of roughly 9°C.

Under these conditions the biogas plants would achieve a profit of 104 thd. € (150 kW_{el} plant), 174 thd. € (250 kW_{el} plant), and 477 thd. € (600 kW_{el} plant). In these profit values **spreading costs for the effluent** are excluded, but accounted for in EU-EFEM. The attribution of spreading costs to biogas production can certainly be discussed controversially, but it seems reasonable to assign them to animal production where manure is the substrate and to biogas production for equivalent amounts of plant substrates.

3.3.5 Emission Accounting

In comparison to other sectors, emission accounting in agriculture is hampered by the fact that agricultural production depends on natural conditions and is mainly area intensive thus abandoning “bottleneck” measurements at hotspots. Even in animal production, animals are often kept outside stables or stables are open, so that emission cannot be measured without biases. As a possible solution, PÉREZ DOMÍNGUEZ (2006) considers a top-down approach that calibrates bottom-up estimates according to discrepancies to measured atmospheric trace gas concentrations. However, this incurs biases arising from unknown or emission sources neglected in the top-down consideration.

Because of the reasons mentioned above, emission measuring is impractible, and for EU-EFEM fixed emission factors represents the procedure of choice despite the inaccuracies linked to it. The Intergovernmental Panel on Climate Change (IPCC, 2006b) provides default emission factors for the main agricultural sources gathered by international surveys. The IPCC method based on default values is widely accepted by the scientific community for its simplicity. However controversies about the coverage of the complexity of GHG emission generation by this mechanism are persistent. In general, IPCC leaves room for three tiers, whereof two tiers are by data of IPCC and the third tier is according to individual approaches if their validity, at least for the country concerned, can be proven. Table 26 gives an overview of options integrated into EU-EFEM for the calculation of GHG emissions. Two options are the IPCC Tier 1- and Tier 2-approach. The third option unifies different calculation methods, sometimes also regionally adjusted IPCC emission factors. The following section is structured according to the availability of the different emission calculation methods under each simulated greenhouse gas and emission source.

Table 26: EU-EFEM's Options for GHG-Emission Calculation

Gas	Emission Source	IPCC-Tier 1	IPCC-Tier 2	Other
methane	enteric fermentation	x	(x)	x
	manure management	x	x	x
	purchased materials			x
	fertiliser production			x
nitrous oxide	*Animal Keeping (EF 3)*			
	manure management	x		
	grazing animals	x		
	Direct Soil (EF 1, (EF 2))			
	N in synthetic fertiliser	x		x
	N in organic fertiliser	x		x
	fertiliser spreading	x		x
	crop residue	x		x
	biological nitrogen fixation	x		x
	Indirect Soil			
	atmospheric deposition (EF 4)	x		
	leaching and run-off (EF 5)	x		
	Others			
	purchased materials			x
	fertiliser production			x
carbon dioxide	fertilizer production			x
	energy use			x
	soil organic carbon accumulation	x		x
	purchased materials			x
	fertiliser production			x
ammonia	manure management			x
	fertiliser spreading	x		x
	fertiliser production			x

Source: own presentation based on IPCC (2006b).

3.3.5.1 Methane Emissions

Most of the methane sources analysed here are linked to animal production, and contribute significantly to total farm emissions. Minor sources like fertiliser production will also be discussed.

3.3.5.1.1 Methane from Enteric Fermentation

In IPCC Tier 1 the emission factors like shown in Table 27 are attributed the source "enteric fermentation". The Tier 1-approach can merely deliver an unclear picture of real emission. This is self-explanatory since the Tier 1-validity is restricted to typical feeding rations and performance levels of the entire Western European climate zone. Extensive free-range bull fattening is treated the same way as intensive stable fattening.

Table 27: IPCC-Tier 1 Emission Factor Enteric Fermentation

Animal Category	**Age**	**Emission Factor**
		(kg CH_4/stable place)
dairy cattle	all ages	100.0
fattening cattle	all ages	84.0
breeding cattle	1st year	33.0
breeding cattle	2nd year	48.0
fattening pigs	all ages	1.5
breeding pigs	all ages	1.5
poultry	all ages	0.0

Source: IPCC (1997b) (IPCC climate zone "Western Europe").

Contrastingly, in the IPCC Tier 2-approach feed intake levels are considered although only at discrete steps of energy uptake. A third approach is presented by Kirchgessner and associates (Kirchgessner et al., 1994) and others. Kirchgessner and associates consider current feed intake and the composition of feeding rations[48]. The used emission factors are gained from a number of (respiratory) experiments on cattle and pigs fed different rations. They formulated a correlation between methane emissions and the nutrient uptake in fats, fibres, proteins and nitrogen-free extracts (see Formula 9 to Formula 11). This alternative achieves by far increased accuracy. Since feeding rations and its major constituents are accounted for anyway in EU-EFEM (within its feeding module), the application of this approach is possible.

Formula 9: Methane from Enteric Fermentation for Cattle

$$\mathrm{CH_4(g/day)} = 63 + 26 \times \mathrm{XP} + 79 \times \mathrm{XF} + 10 \times \mathrm{NfE} - 212 \times \mathrm{XL}$$

with the indexes:

XP	raw protein
XF	raw fibre
NfE	N-free extracts
XL	raw fat

---

[48] Factors that influence the formation of methane during enteric fermentation are named in section 2.1.2.

Formula 10: Methane from Enteric Fermentation for Fattening Pigs

$$CH_4\text{(g/day)} = 2.85 + 13 \times BFS$$

with the index:

BFS	bacterially fermentable substance

Formula 11: Methane from Enteric Fermentation for Breeding Pigs

$$CH_4\text{ (g/day)} = 16 \times BFS$$

As can be seen in Formula 9, the influence of raw fat in rations (XL) on methane emissions is negative, i.e. fat can help reduce levels of methane emission. However, there is a natural limit to this (desired) effect. The authors recommend restricting the fat portion in feed rations to 5% of the total dry matter content for cattle and 10% for pigs. Emissions from enteric fermentation are by far less in other animal categories, and thus they are spared this restriction.

3.3.5.1.2 Methane from Manure Management

In describing the methane emission source “manure management”, it is to be recalled that the formation of methane occurs in anaerobic environments and depends on the availability of organic material. Provided an anaerobic environment is present, methane development depends on the temperature. In IPCC the availability of organic material is expressed by the “methane production potential”, a factor that gives the maximum amount of methane that can potentially be produced from a unit of manure. The climatic conditions are taken into account with the “methane conversion factor”. It depends on the storage type (aerated vs. anaerobic) and the ambience temperature (climate) and defines the portion of the methane production potential that is realised.

Table 28: IPCC-Tier 1 Emission Factor Manure Management acc. to Clime

Animal Category	**Storage System**	**Cool**	**Temperate**	**Warm**
		(kg CH_4/stable place)		
dairy cattle	slurry/ pit storage	14.00	44.00	81.00
other cattle		6.00	20.00	39.00
pigs		3.00	10.00	18.00
sheep	dry lot	0.19	0.28	0.37
goats		0.12	0.18	0.23
poultry		0.78	0.12	0.16

Source: IPCC (1997a).

For the IPCC Tier 1 approach, default values of organic matter content for different types of manure are assumed, and an emission factor is offered which is specific to animal category, type of manure storage, and to clime (Table 28). In the Tier 2 approach, the animal specific methane production potential (MPP) and the methane conversion factor (MCF) are multiplied by the organic matter content of animal excreta in the form of Volatile Solids[49]. The correspondent MPP and MCF values for Western Europe are summarised in Table 29 and Table 30.

Table 29: IPCC-Tier 2 Methane Production Potential (MPP)

Animal Category	**MPP**	**Animal Category**	**MPP**
	(m^3 CH_4/kg VS)		(m^3 CH_4/kg VS)
dairy cattle	0.24	sheep	0.19
other cattle	0.17	goats	0.17
pigs	0.45	poultry	0.32

Source: IPCC (1997a).

Table 30: IPCC-Tier 2 Methane Conversion Factor (MCF) acc. to Clime

Storage System	**Cool**	**Temperate**	**Warm**
		(%)	
liquid manure	10.0	35.0	65.0
solid manure	1.0	15.0	20.0
grazing	1.0	15.0	20.0
daily spread	0.1	0.5	1.0
anaerobic[50]	90.0	90.0	90.0

Source: IPCC (1997a).

The alternative to the IPCC method does not calculate the Volatile Solids content of excreta, but their organic matter content. This is already a coefficient in EU-EFEM, and its determination is thus without problems. Thereby, the model endogenous determination of animal specific excretion rates and the organic matter contents specified for manure types represent worthwhile input parameters. Also, the emissions from manure digested in biogas plants can be integrated easily, since digestion directly affects organic matter contents (see Table 31).

---

[49] In IPCC, not the organic matter content but the Volatile Solids (VS) are considered. Volatile solids are estimated with parameters on ash content of feed, digestibility, and energy density (IPCC, 1997a).

[50] Anaerobic storage system refers to anaerobic digesters.

Table 31: Reduction of Dry Matter by Anaerobic Digestion acc. to Substrate Origin

Animal Category	Breeding	Fattening	Crop Type	Silage
	(% of $DM_{organic}$)			(% of $DM_{organic}$)
cattle	30	45	cereals	70
pigs	40	50	grass	75
poultry	55	65		

Source: AMON and DÖHLER (2006, pp.153f).

Air pollution control programs promote the construction of storage covers for liquid manure systems in order to reduce ammonia emissions and to control methane emissions. KLIMONT and BRINK (2004) assume an intensification of anaerobic conditions leading to an increase in methane emissions by 10%. Due to these contradictory tendencies and their correlation with external factors like temperature or wind, EU-EFEM does not consider any effect on methane emissions from alternative storage covers.

3.3.5.2 Nitrous Oxide Emissions

In agriculture the emission of nitrous oxide is strongly correlated to nitrogen volatility rates. Since volatility is mainly in the form of ammonia, special reference is owed to the proper approximation of ammonia emissions alongside the description of nitrous oxide emissions. All the methods for the determination of nitrous oxide emissions considered in this study are merely different with respect to ammonia emissions. Therefore a separate section is dedicated to ammonia emissions (at the end of this chapter). But first the determination of nitrous oxide emissions will be described. All nitrous oxide estimates will be given in kg N_2O-N, which can be converted to kg N_2O by multiplication with 44/28.

Following the classification made by the IPCC, N_2O-emissions are divided into direct soil and indirect emissions, and emissions from manure management. N_2O-emissions entailed by animal production are negligible in extent[51]. Here, the atmospheric formation of N_2O by oxidation of NH_3 with OH^- and the subsequent chemical reactions are not considered, since this reaction occurs to 95% in tropical and subtropical zones.

---

[51] In the animal's gut organically bound nitrogen and nitrate are simultaneously found. Via dissimilatory processes, nitrate is reduced to NH_3/NH_4^+ and potentially small amounts of N_2O could be released. Due to the highly anoxic environment in the gut, this reductive reaction favours the formation of ammonia and ammonium.

3.3.5.2.1 Direct Soil Emissions of Nitrous Oxide

Within the class "direct soil emissions", IPCC differs between background and fertiliser induced emissions. Background emissions are defined as the emissions that would occur on an unfertilised field (IPCC, 1997) and add up to the fertiliser induced emissions. IPCC suggests estimating direct N_2O-emissions via Formula 12, applying the emission factors EF_1 and EF_2 provided for by BOUWMAN (1994). EF_1 accounts for emissions arising from nitrogen input to the soil, EF_2 accounts for emissions arising from cultivating mineral soils. The values for EF_1 are 0.0025, 0.0125, and 0.0225 kg N_2O-N/kg N for cool, temperate, and warm climes. EF_2 is uniformly 5.0 kg N_2O-N/ha.

Formula 12: IPCC Direct N_2O Emissions from Soils (kg N_2O-N/ha)

$$N_2O - N_{DIRECT} = [(F_{SN} + F_{AW} + 2 \times F_{BN} + 2 \times F_{CR}) \times EF_1] + F_{OS} \times EF_2$$

With:

F_{SN}	Synthetic Nitrogen (kg N/ha) reduced by volatilised N ($Frac_{GASF}$)
F_{AW}	Animal Waste (kg N/ha) reduced by volatilised N ($Frac_{GASM}$) and excluding manure produced during grazing
F_{BN}	Nitrogen input from N-fixing crops (kg N/ha)
F_{CR}	Nitrogen input from plant material left on field (kg N/ha)
F_{OS}	Portion of field that is organic soil (histosol according to FAO definition)
EF_1	Emission factor for direct soil emissions (kg N_2O-N/kg N)
EF_2	Emission factor for organic soil mineralisation (kg N_2O-N/ha)

The IPCC suggests a default value of 3 kg N per kg of grain yield (dry matter) for F_{BN} and 1.5 kg N per kg of crop residues (dry matter) for F_{CR}. Although the described correlation between nitrogen input and N_2O-emissions is strong, there is a certain uncertainty with respect to the determination of the real nitrogen input. This is due to nitrogen losses mainly in the form of ammonia, concerning above all fertilisation with organic and synthetic fertilisers. The determination of ammonia losses is difficult since these depend on a multitude of factors like pH-value, reactive surface between liquid and air, temperature and so forth (compare section 2.1.4). All these factors cannot be captured by IPCC default emission factors $Frac_{GASF}$ and $Frac_{GASM}$, but are partially reflected in the wide range of the same IPCC factors. Further, this multitude of factors is acknowledged by the integration of alternative ammonia loss factors into EU-EFEM. Both the IPCC and the alternative factors are described in the mentioned separate section on ammonia emissions.

3.3.5.2.2 Indirect Emissions of Nitrous Oxide

The category “indirect emissions of nitrous oxide” comprises the sources atmospheric deposition, nitrogen leaching, and run-off (IPCC, 1997a). Atmospheric deposition of nitrogen refers to the process in which nitrogen (in form of NH_3 or NO_x) is deposited from the atmosphere to an ecosystem where nitrous oxide emissions can develop from deposited nitrogen. Atmospheric deposition has a partial circle function, a circle in which nitrogen losses to the atmosphere due to anthropogenic activities (e.g. nitrogen volatisation during fertilization) are partially driven back.

Nitrogen deposited from the atmosphere is subject to nitrogen leaching and run-off if the deposition is to soils (IPCC, 1997a). Table 32 shows the IPCC emission factors of nitrous oxide from nitrogen deposition (EF4) and nitrogen leaching and run-off (EF5). While the first factor depends on the atmospheric nitrogen concentration, the second factor is bound to anthropogenic nitrogen fertilisation. In the European Union, the share of nitrogen being subject to leaching and run-off is estimated by the member states. The estimate is from 10% in Denmark to 31% in Ireland (see the yearly “National Greenhouse Gas Inventory” provided for by each EU member state).

Table 32: IPCC N_2O-Emission Factors “Indirect Soil” acc. to Clime

Factor	Source	Unit	Cool	Temperate	Warm
EF4	N deposition	(kg N_2O-N/kg NH_3-N or NO_X)	0.002	0.010	0.020
EF5	leaching / run-off	(kg N_2O-N/kg N)	0.002	0.025	0.120

Source: IPCC (1997a), p. 4.105.

3.3.5.2.3 Nitrous Oxide from Manure Management

The formation of nitrous oxide in manure management is through the processes of nitrification and denitrification of ammoniacal nitrogen. The IPCC suggests estimating the N_2O-source “manure management” with fixed factors specified according to storage system and storage duration. As third factor, the oxygen level in the storage system is neglected by the IPCC because it saw too few quantitative data on which to formulate a correlation (IPCC, 1997a; p. 4.95). Under completely aerobic conditions nearly no nitrous oxide generates. The IPCC factors are shown in Table 33.

Table 33: IPCC N_2O-Emission Factors “Manure Management” acc. to Clime

Storage System	**Cool**	**Temperate**	**Warm**
		(kg N_2O-N/kg N)	
liquid manure	0.001	0.001	0.001
solid manure	0.005	0.020	0.030
manure from grazing animals	0.005	0.020	0.030
anaerobic digesters	0.001	0.001	0.001
daily spread	0.000	0.000	0.000

Source: IPCC (1997a), p. 4.104.

There is the possibility to reduce nitrous oxide emissions from manure management in case of liquid open storage systems. Emissions can be reduced by means of installing storage covers. KLIMONT and BRINK (2004) estimated the reduction potential to be in the range of 10%. Because of an only small number of experiments, this result is not utilized in this study.

3.3.5.3 Emission Sources Linked to Agricultural Production

In contrast to the above emission sources, not all of the following emission sources are linked to agricultural production according to the IPCC categorisation and the Kyoto Protocol: fertiliser production, purchased materials, and energy consumption are listed under the corresponding industries of origin (NATIONAL INVENTORY GUIDELINES, 2003). However, fertiliser is produced for agriculture, and in the model the exclusion of emissions from the production of feedstock would push farmers to outsource feed production under an emission taxation scenario, an unwanted reaction.

3.3.5.3.1 Fertiliser Production

Emission factors that take into account the emissions occurring in the production process of synthetic fertilisers are available. Here only those factors being applicable to the fertilisers simulated in this study (see section 3.3.3) will be cited. In terms of nitrogen fertilisers, the restriction is to the two categories of urea and non-urea fertilisers. In terms of other fertilisers, only for average phosphate, average potash, and for average calcium fertilisers specified emission factors were available utilized. The utilised emission factors are mainly country specific WOOD and COWIE (2004).

Table 34: GHG Emissions from Production of Urea and Non-Nitrogen Fertilisers

Fertiliser Class	**CH_4**	**N_2O-N**	**CO_2**
		(kg/dt nutrient)	
urea	0.411	0.002	391.8
average phosphate	0.260	0.004	98.0
average potash	0.139	0.005	62.0
average calcium	0.029	0.002	28.0

Table 34 shows the values average of values utilised in EU-EFEM. Under the precondition of availability, the more detailed national factors shown in Table 35 were applied. That maintaining a separation between urea and non-urea fertilisers also makes sense with respect to emissions can be seen from the comparison of both tables where very different emission values manifest.

Table 35: GHG Emissions from Production of Non-Urea Nitrogen Fertilisers

Country	**CH_4**	**N_2O-N**	**CO_2**	**Country**	**CH_4**	**N_2O-N**	**CO_2**
		(kg/dt Nutrient)				(kg/dt Nutrient)	
Austria	0.309	1.370	329.5	Ireland	0.317	1.307	351.9
Belgium	0.315	1.325	325.2	Italy	0.370	0.957	414.9
Denmark	0.317	1.283	345.4	Netherlands	0.327	1.290	341.2
Finland	0.323	1.224	378.7	Portugal	0.340	1.148	365.4
France	0.324	1.082	338.6	Spain	0.349	1.061	381.9
Germany	0.313	1.278	316.7	Sweden	0.327	1.158	348.0
Greece	0.382	0.864	434.7				

Source: WOOD and COWIE (2004).

Ammonia Emissions

Among other ceilings, the Gothenborg Protocol (see section 2.2) sets one for ammonia emissions. This is of relevance to agricultural fertilization practices. The National Codes formulated by EU member states as a reaction to the Gothenborg Protocol give recommendations on fertilization (organic and synthetic) and recommend the use of catch crops to reduce nitrogen concentrations in agricultural soils. Apart some member states oblige farmers to use best available technique in fertilisation. The technique shall, for example, avoid surface spreading of manure, incorporate nitrogen fast into soils. As regards mineral fertilisers, the application of ammonium carbonate has been banned.

Organic Manure

During the field application of liquid manure (slurry), the volatisation rate of animal waste ($Frac_{GASM}$) as ammonia is between 10% and 37% according to IPCC (1997a), independently of animal species. Alternative sources quantify emissions in more detail and on the preferred level of EU-EFEM periods, as shown in Table 36. Unfortunately such values were not found for pigs and cattle. The volatisation rate for solid manure is indicated with 30% according to IPCC and with 60% according to the alternative source.

Table 36: (Non-IPCC) Ammonia Loss Rates in Slurry Application acc. to Clime

	Cattle			Pigs		
Period	**Cool**	**Temperate**	**Warm**	**Cool**	**Temperate**	**Warm**
		(kg NH3-N/kg N)			(kg NH3-N/kg N)	
Mar	0.21	0.35	0.90	0.12	0.20	0.50
Apr-Jul	0.33	0.55	0.90	0.18	0.30	0.50
Aug	0.54	0.90	0.90	0.30	0.50	0.50
Sept-Oct	0.33	0.55	0.90	0.18	0.30	0.50
Nov-Feb	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Source: KTBL *(2000),* UBA *(2002), and* MENZI *et al. (1997).*

Because some sources define different ammonia loss rates according to the application technology, EU-EFEM considers three technology options as ammonia reduction options. The technology's categorisation is into “base”, “low efficient” and “high efficient”. The functioning of the more efficient categories aims at minimising the exposure of manure to open air, by reducing either the exposure duration or the contact surface. As can be seen in Table 37, more efficient technology in solid manure is only available for arable land. This technology consists in immediate or fast incorporation into the soil (before 24 hours). For liquid manure, more efficient treatments are available for arable land and grassland. The available treatments and their specific reduction of ammonia loss rates are listed in the table.

Table 37: Reduction of Ammonia Losses in Manure Application

Land Use	**Efficiency**	**Manure**	**Technology**	**Efficiency Rate**
grassland	low	liquid	trail hose	40%
		solid	n.a.	--
arable	low	liquid	trail hose	40%
		solid	fast incorporation	20%
grassland	high	liquid	n.a.	--
		solid	n.a.	--
arable	high	liquid	injection	80%
		solid	immediate incorporation	80%

Source: based on KLIMONT *and* BRINK *(2004).*

A further hotspot of ammonia emissions in agriculture is the animal keeping itself. Losses are from manure storage and housing. In manure storage emissions occur to the extent described in Table 38. Possibilities for emission reduction consist in straw or solid covers put onto the storage facility. The assumed emission reduction achieved by these measures is shown in the same table.

Table 38: Ammonia Losses in Manure Storage and Reduction of Losses

	Animal Group			**Reduction**	
Manure Type	**Cattle**	**Pigs**	**Poultry**	**Straw Cover**	**Solid Cover**
	(kg NH_3-N/kg NH_4-N)				
liquid	0.15	0.23	0.05	55%	90%
solid	0.20	0.20	0.20	n.a.	n.a.
anaerobic (liquid)	0.05	0.08	0.02	n.a.	n.a.

Source: LOETHE *(1999),* TOP AGRAR *(2002), and* KLIMONT *and* BRINK *(2004).*

The emissions from housing are mainly determined by housing type and manure removal frequency. The housing type is the factor that is important as regards to wind exposure (contact surface) and indoor temperatures. The manure removal frequency is the factor that is important as regards to bacterial activity, since a high frequency bars bacteria from nitrification processes. In EU-EFEM, only a default emission factor from housing is assumed, due to the number of unknowns. For housings based on liquid manure systems, 10% of the excreta's NH_4-N is assumed to vaporize as NH_3-N. For housings based on solid manure systems 20% is assumed.

Synthetic Fertilisers:

It has previously been described how both the application and the production of nitrogen fertilisers translate into nitrous oxide emissions. Also, in this case, nitrous oxide emissions coincide with ammonia emissions. In nitrogen fertiliser plants, ammonia emissions are assumed to be in the range of 0.669 kg NH_3-N per 100 kg N produced (equal to 0.551 kg NH_3). For other fertiliser types, ammonia emissions are negligible and are assumed to be zero.

With respect to ammonia emissions from the application of nitrogen fertiliser, two groups of fertilisers are distinguished in EU-EFEM. These groups are urea and non-urea which both show very different ammonia loss rates. The IPCC methodology does not account for this difference, at least not directly, but gives country specific loss rates implying average ambient temperatures. The IPCC ammonia loss rates

($Frac_{GASF}$) range from 0.6% in Finland to 10.0% in France, Germany, Italy, Portugal and Spain. An alternative source discriminates urea against non-urea fertilisers and also accounts for the ambient temperatures in the place of application. Even within the same climate zone, values differ by up to the factor five, as can be seen in Table 39.

Table 39: Ammonia Loss Rates of Fertilisers acc. to Clime

Clime	**Urea**	**Non-Urea**
	(kg NH3-N/kg N)	
cool	0.10	0.02
temperate	0.15	0.05
warm	0.20	0.08

Source: own calculation based on EEA, and DAEMMGEN *and* GRÜNHAGE *(2001).*

3.4 Regional Production Costs in Plant Production

EU-EFEM's objective function is the maximisation of the total farm gross margin, which is defined as the sum of revenues less variable costs. The analysis of fixed costs is thus exuberant. A new approach will be introduced for estimating variable costs; however being restricted to plant production costs. Variable costs of livestock production will be estimated following a known standard cost approach taken already in older model versions of EU-EFEM.

In the following, first the estimation of crops under conventional tillage and second the estimation of crops under conservational tillage will be presented. At the end of the section, results obtained with the approach will be presented in the form of EU-wide (EU-15) cost estimates for several selected crops.

The motivation to conceive a new approach for estimating variable costs in plant production was that so far farm level studies had to use standard cost data. But standard cost data neglect or simplify farm specific cost situations and/or local conditions. In view of the regional scope of EU-EFEM, spanning the entire EU-15, and its regional heterogeneity, this disadvantage would even have intensified.

3.4.1 Combining Accountancy Data and Engineering Costs

The current approach exploits two data sources whereof the first contains accountancy data and the second default engineering costs. The ***strength of the current approach*** lies in:

- Bridging the missing crop specificity of the accountancy data, and
- Bridging the missing region specificity of the engineering cost data.

The applicability of the approach had to be restricted to crops under conventional tillage, because the accountancy dataset does not discriminate costs of conventional against conservational tillage. So, for reasons of simplicity, it was assumed that in the used 2001- 2003 accountancy data no conservational tillage was contained which might only be true for no-till, but not for mulch seeding (compare Table 19). The bias provoked by this simplification, however is not too strong, since variable costs of conventional and conservational tillage only slightly vary.

The ***core assumption*** of the current approach is the following:

The relation crops of a certain *farm X* would have according to the engineering cost approach can be copied to the accountancy data in order to also achieve crop specificity for the accountancy data.

The motivation for aiming at achieving crop specificity for the accountancy data is that in comparison to the engineering cost data, it has EU-15-wide representation and is developed from a larger sample, it is yearly and actual data, and it is per NUTS-II region, i.e. the finest regional resolution of this study.

The applied accountancy data used is from the Farm Accountancy Data Network (FADN). Established by the European Commission in 1965, the FADN is the only Europe wide and harmonized source of micro-economic data on agriculture. It makes EU member states to collect data in ample surveys on accountancy parameters like factor expenditures, farming income, and factor capacities, but also classifies farms according to regional membership, farm size, and type. The level of detail of the accountancy parameters is thereby not on single crops, but on production branches (animal or plant production).

In the applied engineering cost database costs are defined crop specific and per field activity. The latter is a great advantage of this German database when it comes to the definition of costs for conservational tillage. The approach applied for conservational tillage merely adds the costs per additional and subtracts the costs per exuberant field activity proportionally. Otherwise, other standard gross margin databases could have been applied alternatively. The approach to estimate costs of conservational tillage will be introduced in the next section.

The applied database of engineering costs is from the *Kuratorium für Technik und Bauwesen in der Landwirtschaft* (KTBL, 2003). Though a unique database with respect to data detail and the span of farming technologies being considered, it only represents German farms. For decades KTBL has been a very popular auxiliary for a number of profitability calculations on German agriculture. The KTBL engineering cost data is also used to deduct standard gross margins that have to be submitted to the FADN network by member states every two years. Like the FADN data, it is based on sample data, although on a smaller sample, but appended by valuable expert knowledge. The level of detail of the cost parameters of KTBL is on single crops. The cost parameters are classified according to climatic conditions, field plot sizes, technical equipment, and field activities.

Apart from the larger geographic extent of the FADN data and the more up-to-date validity of the data, it is also a micro-economic theory that speaks for the utilisation of FADN instead of KTBL data. In micro-economic theory, economies of scale and economies of scope are important. Often engineering cost approaches will not allow accounting for economies of scope. Only because of its considerable level of detail and the classification of costs values according to field plot sizes or technical equipment is it possible to modify cost values. This, however, requires information on field plot sizes and technical equipment. Economies of scope work towards a higher degree of specialisation. But the cost effect of specialisation is not straightforward and is difficult to capture with an engineering cost approach.

In conclusion, three main problems are faced when production costs are estimated with an engineering cost approach:

1ST: Despite KTBL's high level of detail, the intersection of default costs with the cost situation of real farms remains difficult since farm information that is usually detailed, about single field sizes, machinery equipment, field-farm distances, and other structural parameters, is not available. The single possible way to obtain such information would be by time-consuming farm surveys. The analysis of imaginary farms, like the EU-EFEM farms, completely debars this option.

2ND: The bulk of factors affecting farm structure (e.g. natural conditions or managerial skills) are not captured entirely even though farm structure has an impact on production costs.

3RD: Some farm structure building factors might not be (economically) quantifiable (e.g. managerial skills).

Costs declared in farm accountancy data, in contrast, imply all these factors (natural conditions, managerial skills, etc.), because they are for a given farm and not averaged over a group of farms. However, in the available FADN accountancy data there is only an attribution of costs to the plant and the animal production branch, but not to single crops. How to overcome this disadvantage will be presented in the following.

After the expected advantages of joining the two different data sets of FADN and KTBL have been explained, their conformity to each other shall be briefly verified. In both KTBL and FADN, total variable costs are made up of single cost items. Apart from the specification which, as already mentioned, is different in both bases, it can be seen in Table 40 that the main cost items are available in both: input factor costs (fertilizer, seeding, plant protection, and miscellaneous factor costs), machinery costs, and contract work are groupings. The most striking differences can be stated for “wages paid” and for “interest on circulating capital”. The first is missing in KTBL, the second in FADN.

Table 40: Comparison of KTBL and FADN Cost Items

Nº	**Cost Item**	**KTBL-Specification**	**FADN-Specification**
1	Factor Cost (seeds, fertiliser, etc.)	crop	production branch
2	Maintenance of Machinery and Equipment	crop	farm
3	Fuel and Lubricant	activity	farm
4	Electricity and Heating	activity	farm
5	Contract Work	crop	farm
6	Wages Paid	n.a.	farm
7	Interest on Circulating Capital	crop	n.a.

3.4.2 General Description of the Approach

In the first step, the engineering costs published by KTBL were taken to determine default values for crop specific production costs. As a preparatory step, this procedure demands the stipulation of crop specific production practices. In KTBL the original costs are per production practice, which means that the production costs of a certain crop according to KTBL will depend on the combination of production practices done on the basis of the crop’s cultivation. The stipulation of production practices is made once per crop, and then is applied uniformly across all regions. At first glance this seems a very strong restriction, but the main characteristic of the current approach is that the KTBL costs in the end do not matter as to their absolute value, but only as to the relative value.

Again, in the end only the relative value of the default production costs estimated based on KTBL is of importance. In a second step, the relation between the KTBL production costs is given expression. This is done with the farm-specific value “CRP_REL”. Its calculation is according to Formula 13. With CRP_REL the relation of costs between all crops grown by a certain farm which they would have according to KTBL is given to. It is then assumed that this relation was always present in all farms.

Formula 13: Farm-Specific Relation between Crop Production Costs

$$\mathrm{CRP\_REL}_{(farm,item,crop)} = \mathrm{Kcost}_{(item,\ crop)} \times \mathrm{Farea}_{(farm,\ crop)} / \textstyle\sum_{crop}, \mathrm{Kcost}_{(item,\ crop)} \times \mathrm{Farea}_{(farm,\ crop)}$$

with the indexes:

farm	FADN farm
item	cost item
crop	crop

and the parameters:

Kcost	crop specific KTBL costs
Farea	crop specific area on FADN farm

For illustration purposes the deduction of “CRP_REL” for the cost item “*fuel and lubricants*” is presented at an imaginary farm. This farm grows two types of crops, wheat and grain maize (Table 41). The calculations from row 1 to row 5 deliver the values of 0.56 and 0.44 for CRP_REL grain maize and CRP_REL wheat. Summing all CRP_RELs under a certain cost item always gives 1, here for “*fuel*”: 0.56 + 0.44 = 1.00. This is equal to a redistribution of 100% of declared FADN fuel costs.

Table 41: Calculation of ‘CRP_REL’ for Fuel Illustrated at an Imaginary Farm

Nº	Action	Title	A: Wheat	B: Grain Maize
1		KTBL fuel costs (€)	40.0	90.0
2		farm crop area (ha)	30.0	10.5
3	1 × 2	priority numerator	40.0×30.0=1,200	90.0×10.5=945
4	3A + 3B	priority denominator	(40.0×30.0)+(90.0×10.5)=2,145	
5	3 ÷ 4	CRP_REL*	1,200÷2,145=0.56	945÷2,145=0.44

** “Priority Coefficient”*

Before proceeding, the structure of the engineering cost approach to determine production costs is to be reconsidered. For the determination of production costs, it is necessary to define crop specific production practices. Usually defined on a per hectare basis, the extent of some practices depends on the harvested yield. An intersection with yield data preferably on regional scale is thus indicated[52]. With the definition of production practices per hectare and per unit of yield, and with regional crop yields, all data are at hand to generate a KTBL based estimate of default costs like the example shown in Table 42. There, production costs of winter wheat and rye are listed for the arbitrary chosen region Stuttgart. Transport costs are based on a uniform definition of farm-field distance at four kilometres.

Table 42: Default Costs in Wheat and Rye Production (Example Stuttgart)

Process	**Trips**	**Reference**	**Costs**	**Diesel**	**Electricity**
	(number)		(€)	(l)	(kWh)
ploughing	1	per ha	35.49	25.7	--
field tilling	2	per ha	13.52	8.9	--
base fertilization	2	per ha	3.15	1.4	--
combined rotary harrow	2	per ha	11.00	7.8	--
sowing	1	per ha	8.14	5.1	--
foliar fertilization	3	per ha	2.29	1.0	--
spraying	4	per ha	4.07	1.3	--
harvesting	1	per ha	21.79	15.0	--
transport	1	per dt	0.33	0.2	--
grain drying	1	per dt	0.14	0.3	0.2
total winter wheat (yield 62 dt)		**(per ha)**	**172.79**	**123.2**	**12.4**
total rye (yield 56 dt)		**(per ha)**	**170.00**	**120.0**	**11.2**

Source: own calculation based on KTBL (2003).

Similarly to the example above, production costs according to KTBL are estimated for all crops contained in the FADN data set, apart from potatoes. They merit special attention since the production costs depend on the type of final consumption of the potatoes. According to the type of consumption, breeds are classified into seed, table, feed and starch potatoes, while starch potatoes are for human or animal nutrition. For this study the differentiation between starch and feed potatoes is irrelevant, since the study focus lies on farm level production costs, which are the same for both, and only processing is different. The production costs of potatoes include all processes from seedling conservation until sale, including storage and sorting as decisive cost items. The storage duration and thus the storage costs are defined per type of breed. Seed potatoes are assumed to be stored for six months

---

[52] In theory, regional yield data could be copied from FADN or from EUROSTAT (Statistical Office of the European Communities). EUROSTAT is preferred since it gives time series data (ten harvests) and surveys which are on regional and not on a farm level.

(time span between harvesting and seeding), table potatoes for four months, and starch potatoes for two months (KLEFFMANN, 2005). Some sorting is assumed exclusively for table potatoes, for which it is generally necessary to separate out damaged fruits. In the FADN dataset there is no specification of potato breeds. Other sources had to replace this information. EUROSTAT publishes data on potato areas, starch quotas, mean starch contents, and breed specific seed quantities on a national level, whereby the shares were transferred to the FADN farms uniformly.

Generally speaking, the procedure for grassland crops is the same as that for arable crops. However, the main problem arises from the enormous production diversity for grassland across the EU. A uniform definition of production practices did not seem appropriate. It was decided to distinguish between five levels of production intensity instead. The production intensity was defined by the number of cuts of the plant stand. In the EU, a minimum of one cut is obligatory in terms of agricultural policies and a maximum of five to six cuts is possible due to natural and economical limitations. The number of cuts is defined per region (compare chapter 3.3.3). Since grassland products can be harvested in many different forms, from hay to green fodder, or from loose fodder to baled hay, the definition of uniform practices, especially transport and harvest, cannot be as accurate as for arable land. Some simplifications had to be made. If hay or silage is sold, off-farm transport and conservation costs are excluded from the definition of KTBL costs and are only charged to the sale prices.

3.4.3 Detailed Description According to Cost Items

Because of high inter-annual variation in some of the cost items of the FADN data, the calculation of CRP_REL cannot always be straightforward. For the minimisation of the annual influence, a special procedure has been applied. This will be explained in the following at each single cost item. A summarising table is attached at the end of the section.

3.4.3.1 FADN Cost Item 1: Factor Costs for Purchased Materials

The redistribution of cost for “*purchased materials*” from the FADN accountancy data is not according to the described standard procedure (see above). This is due to different reasons. The most important input factors that fall under the category “purchased materials” are mineral fertilizers and purchased seeds. Both factors experience a special treatment, in EU-EFEM and in the estimate of their costs, which will be described in the following.

3.4.3.1.1 Mineral Fertilizers

Due to its relation to yields and its potentially harmful effect on the environment, the use of mineral fertilizers is a model endogenous variable in EU-EFEM. It is steered by production functions and fertilizer costs. In combination with national mineral fertilizer prices, this allows for a detailed simulation of mineral fertilizer costs in EU-EFEM. An estimate of mineral fertiliser costs based on the values in the accountancy data is thus unnecessary.

3.4.3.1.2 Seeds

In comparison to "*mineral fertilizer*", the characteristic of "*seeds*" is completely different, although both are "*purchased input materials*". Mineral fertiliser is a necessarily purchased material, in contrast to seeds which is a facultative purchased material. If farmers want to use mineral fertilizer they have to buy it. If farmers want to use seeds they can either buy them or reproduce them from their own seeds harvested in previous seasons. This has to be qualified since breeds like hybrid seeds cannot be reproduced from one generation to the next.

The issue of defining default farm expenditures on purchased seeds is thus dominated by three questions: a) the share of seeds purchased and reproduced on farm, b) the price of purchased seeds, and c) eventual reproduction licenses to be paid to the owner of the property rights.

The first, the share of seeds purchased and reproduced on farm, unfortunately, is a no-show in the FADN accountancy data. The standard procedure of the approach introduced here, with the intersection of engineering and accountancy data thus falls through. Alternatively, crop and country specific average shares were assumed. An example thereof can be seen in Table 43. It shows the composition of seed costs for potato under average conditions in Germany.

Table 43: Composition of Potato Seed Costs by 2003 (Example Germany)

Nº	Item	Unit	Calculation	Costs
1	seed quantity	(dt/ha)		28.00
2	share of certified seeds	(%)		21.00
3	share of own seeds	(%)		79.00
4	price certified seeds	(€/dt)		43.20
5	sales value crop	(€/dt)		4.89
6	seed dressing	(€/dt)		4.80
7	licence fee	(€/dt)		6.75
8	paid percentage of licence fee	(%)		30.00
9	costs reproduction under licence	(€/dt)	(=7×8)	2.03
10	costs own seeds	(€/dt)	(=5+6+9)	11.72
11	**total seed costs**	**(€/ha)**	**(=10×3×1+4×2×1)**	**513.26**

Source: LFL BAYERN *(2003).*

The second and third question on the price of purchased seeds respective license fees payable for own reproduced seeds would usually be answered by drawing back on the mentioned KTBL data base. Since this only represents German farms it cannot capture the entire range of seed costs in the EU-15 and the range is wide with a variation by up to 250% between the cheapest and the most expensive national value according to BROOKES (2000). That is why the European data, mainly from Brookes, is preferred against the KTBL seed costs. Linked to the costs of own reproduced seeds is also the reduction on marketable yield. The seeds taken for own reproduction purposes are from a farm's previous harvest. This context is observed in the current study.

3.4.3.2 FADN Cost Item 2: Maintenance of Machinery and Equipment

In general, the redistribution of "*machinery and equipment*" costs from the FADN accountancy data is according to the described standard procedure (see beginning of this section). The only problem concerns machinery costs arising from the spreading of fertilizers. The problem is in the definition of "*fertilizer spreading*" as a standard production process, since its value correlates to the applied quantities of fertilizers. The applied quantities, again, are determined in the solve process of EU-EFEM (applied quantities of mineral fertilizers are determined by a model endogenous variable; applied quantities of organic fertilizers are equal to the amounts of accruing manure from animal production). Thus, in the context of defining a standard production process "*fertilizer spreading*" average application amounts per hectare could only be assumed. In order to achieve maximal accuracy, while empirical data for the EU-15 is not available, the average application quantities were regionally specified, proportionally to the average empirical yields from the EUROSTAT database.

This alternative procedure is only available for mineral fertilizers where a relationship between yields and application amounts was assumed. Application amount and hence spreading costs for organic fertiliser, in contrast, depend on accruing manure amounts and in consequence will only be found on animal keeping farms. In theory, farm specific spreading amounts could be deduced from the empirical number of animals kept and default excretion rates. Default excretion rates show, however, a wide range of variation, since manure is not equal to nutrient excretion, but also may or may not include litter material. Whether litter is applied or not is, in the majority of cases, linked to the housing type, a parameter for which data is not contained in the FADN dataset or alternative reliable datasets. Finally, the bias from this data to the model could only be reduced by also assuming uniform spreading amounts.

Apart from spreading costs, there are further machinery costs that only occur on livestock farms, but that at the same time are difficult to reflect with KTBL's engineering cost approach, i.e. the first step of the standard procedure of the presented approach for the redistribution of FADN accountancy costs. Examples include work linked to livestock production like milking or putting up fences for grazing cattle. Since all this is extra work that will occur on some livestock farms, but not on all of them, a new control coefficient was introduced. This control coefficient opposes the results from the estimated values of costs to the expected costs, i.e. the costs according to KTBL. The coefficient is drawn for livestock keeping farms and for other farms. It turned out that there were more negative deviations across livestock farms, i.e. that the original formulation of KTBL engineering costs was too low. It was decided to include additional engineering costs. The additional engineering costs were included to the crop “grassland”, which is the only crop that is exclusively found on livestock farms. In an iterative process, additional costs were included for grassland until the coefficient of control showed similar deviations between results from the estimated costs to the KTBL-costs both for livestock and non-livestock farms.

3.4.3.3 FADN Cost Item 3: Fuel and Lubricants

In general, the redistribution of "*fuel and lubricant*" costs from the FADN accountancy data is according to the described standard procedure (see beginning of this section). The definition of standard production processes, as mentioned, includes all processes from seeding to harvest. In the case of outsourced harvesting, the practices taken over by the service provider had to be excluded. The service provider includes the fuel and lubricants for the provided practices in his bill.

Although the approach is based on the application of a standard definition of production practices, the costs per practice copied from KTBL were slightly modified according to country. This modification is due to the fact that KTBL as a German database bases its cost estimates on German fuel and lubricant prices. The applied version of KTBL used prices for fuel of 0.54 €/l and for lubricants of 2.00 €/l. These costs were modified with national average prices from 2000 to 2002 (EUROSTAT, 2006).

3.4.3.4 FADN Cost Item 4: Electricity and Heating

The standard procedure (see beginning of this section) cannot not be applied to the redistribution of the cost item "*electricity and heating*". In the FADN "*electricity and heating*" is per farm and not attributed to the production branches "*animal production*" or "*plant production*" like other cost items. FADN costs are thus not redistributed, but are replaced directly by KTBL default costs. In animal production, electricity is considered for lighting, heating and major electric devices like milking machines. In plant production only costs for grain drying and storage are considered, others are considered marginal and are neglected.

3.4.3.5 FADN Cost Item 5: Contract Work

Prevailing in estimating production costs is the most accurate redistribution of contract work expenditures, because these potentially make up a large share of the production costs. The standard procedure for the redistribution of FADN accountancy costs under "*contract work*" based on KTBL standard values cannot be purchased. An engineering cost approach like KTBL cannot define contract work as a standard production process since the decision whether certain processes are executed by the farm enterprise itself or by contracted service providers is individual. This study attempted to identify rules or schemes behind the decision by farmers for or against contract work for distinct production processes. In order to deduce contract work costs for the analysed FADN farms, the searched rules or schemes must be relatable to the farm specific parameters contained in the FADN.

From an economic viewpoint the decision will be taken in favour of contract work if service costs (including opportunity costs of own labour) are lower than the farmer's own costs would be. From the FADN data set neither the cost to farmers of certain production processes nor the opportunity costs of labour can be read. Reasons other than economic are suspected in the area of farm management and work loads. It can be assumed that especially work that falls together with seasons of high work load, work will be outsourced. Work load and economic reasons are finally assumed to be the two most important motivations for outsourcing certain work.

From the economic point of view, an argument for outsourcing is adherent to high fixed costs. High fixed costs are in such production processes where relatively high investment costs coincide with relatively few hours of use. Both conditions are fulfilled by harvest processes. Additionally, on many farms, especially on plant production farms, peaks of work load are during harvest. With rougher climatic conditions this correlation is tightened, since the time corridor for harvesting narrows. Since economic and management (cutting peaks of maximum work load) reasons fall together for harvest processes, the current approach exclusively focuses on harvest processes for the redistribution of FADN contract work costs.

In the next step and in accordance with the general procedure of this new approach, standard processes were formulated and monetarised. Against the background of adherent high fixed costs, it was decided to group crops according to similar harvesting technology. The grouping is illustrated in Table 44. The harvest technology can either be a certain harvester or a certain harvester in combination with accessories like appended cutting units.

Table 44: Attribution of Crops to Harvest Technology and Accessories

ID	Crop	Combined Harvester	Forage Maize Harvester	Beet Harvester	Other Fodder
1	grain maize	+ maize picker			
2	other cereals	standard			
3	field bean, rapeseed sunflower	+ cutting unit			
4	silage maize		standard		
5	sugar/ fodder beet			standard	
6	potato			+ potato lifter	
7	grass, green clover				standard

In a further step, the expected costs for the really grown crops (by a FADN farm) are then fed into a threefold routine which checks (1) which crop groups are represented, (2) if the FADN costs of a crop group surpass a given lower bound based on the engineering cost value, and if yes, (3) if the FADN costs do not exceed a given upper bound based on the engineering cost value. For arable land the lower bound is 70% of the KTBL costs[53] and the upper bound is 120% of the KTBL costs. For grassland, with its larger variety in management and costs, wider bounds are set.

The threefold routine is not run through simultaneously by all crop groups, but iteratively. A checking order is established which orientates by the level of investment cost of the corresponding harvest technology, i.e. the higher the investment cost, the higher the checking priority. It is reasoned that for farmers it is most attractive to outsource in first place most expensive technology. The established checking priority is the same for all farms. Seven crop groups representing all potential crops are categorised as displayed in Table 45.

Table 45: Checking Priority of Crop Groups

Crop Group (acc. to Harvest Technology)	Priority
all arable crops	1ST
all grassland crops	1ST
crops for beet harvester	2ND
crops for forage maize harvester	3RD
crops for combined harvester	4TH
other fodder crops (grassland technology)	4TH
single crops	5TH

---

[53] The allowed deviation is not equal in both directions since KTBL-values representing German farms probably are a bit above the European average thus justifying higher negative than positive deviations.

However, FADN contract work costs will not always be represented by only one crop group. Rather, for most of the analysed FADN farms, contract work costs will originate from a combination of several crop groups and it can only be satisfactory if all and not only parts of the FADN contract work costs match with the expected contract work costs according to KTBL.

In order to analyse if a combination of crop groups matches FADN costs better than a single crop group, a routine is fed with a stepwise series of data queries. These, as already described, do verify if FADN costs keep a given lower and upper bound deduced from expected KTBL costs. Thereby each series features a finite number of steps. As the stepwise series follows a certain hierarchy according to the shown crop priorities, this series could also be illustrated in the form of a decision tree.

Each step of the series is characterised by a unique combination of nodes reflecting a unique combination of crop groups. The values of the nodes (upper and lower bound, i.e. ±variation of the KTBL-value) within a step of the routine always depend on the result of the previous node. The bounds of a subsequent node are calculated by subtracting the KTBL-value cumulated up to the current node from the FADN-value, in other words the cumulated expected costs are subtracted from the real costs. Since the depiction of the entire decision matrix and its nodes is too dense to be done here, only an excerpt will be illustrated and explained in the following.

In a first step, it is always verified if crops from arable and grassland are available on the actual farm and if all crops of arable land and grassland[54] together match the lower and upper bound (Table 46, Step 1). If so, the stated FADN contract work costs are redistributed to all crops (result ‘R0’). If not, already various branches of the decision matrix have to be queried simultaneously.

If the first step is negative, then, it is queried in a second step (Table 46, ‘Step 2’) if the crops of grassland or arable land alone match the corresponding bounds. For example, if only arable land would be available and arable crops would fit the corresponding bounds, then result ‘R1’ would be chosen (Step 2, 1st Node would be *allgr* = *n.a.-n.a.*, and 2nd Node would be *allar* = *yes-no*).

---

[54] This includes crops of arable land that are harvested with harvesting technology of grassland, e.g. green clover.

Table 46: Extract of Decision Matrix for Redistribution of Contract Work Costs

	1st Node			**2nd Node**			**3rd Node**			**4th Node**			
Step	**Group**	**low**	**up**	**Group**	**low**	**up**	**Group**	**low**	**up**	**Group**	**low**	**up**	**Result**
1	allcr	yes	yes										R0
2	allgr	n.a.	n.a.	allar	yes	no							R1
		yes	yes		n.a.	n.a.							R2
3	allar	no	no	scnd	yes	yes	flwg	no	no				R3
					yes	free	third	yes	yes	flwg	no	no	R4

**: allcr: all crops of grassland and arable land; allgr: all grassland crop groups; allar: all arable land crop groups; flwg: crop groups of lower priorities; scnd: crop group of second priority; third: crop group of third priority; free: yes or no (condition fulfilled or not); n.a.: crop(s) of this category not cultivated.*

In other words, in 'Step 1' to 'Step 3' in Table 46 it is generally answered the question if grassland or arable crops together, or if either grassland or arable crops alone, or if a second priority group of arable crops (second priority are crops for beet harvester) can justify the stated FADN contract work costs. It is thus verified if the stated FADN contract work costs fall in-between the bounds of expected costs of a certain hierarchy of crop groups while expected costs are defined according to KTBL.

The interpretation of the results 'R0' to 'R4' from Table 46 is the following: 'R0' of Step 1 is for the case that the FADN costs (real costs) of all cultivated crops of grassland and arable land together fall into the bounds of KTBL costs (expected costs) (*allcr* = *yes*-*yes*). The redistribution of FADN costs is illustrated in Table 47. In this case FADN costs are redistributed to all cultivated crops (according to CRP_REL). 'R1' of Step 2 is for the case no grassland but only arable crops are cultivated (1st node: *allgr* = *n.a.-n.a.*) and FADN costs are above the upper bound of the KTBL costs for these arable crops (2nd node: *allar* = *yes-no*). Since no other crops are available to which to assign FADN costs, there is no redistribution of FADN costs, at all. 'R2' of Step 2 is for the case no arable but only grassland crops are cultivated and FADN costs fall in-between the bounds of the KTBL costs for these grassland crops (1st node: *allgr* = *yes-yes*, 2nd node: *allar* = *n.a.-n.a.*). The FADN costs thus are redistributed in their full extent to the grassland crops. 'R3' of Step 3 is for the case none of the previous conditions is matched, FADN costs are too low to be expected from all arable crops together (*allar* = *no-no*), and the second priority crop group matches the bounds (*scnd* = *yes*-*yes*) while the crops of the following priority do not match the respective bounds (*flwg* = *no-no*). FADN costs are redistributed to crops of second priority thus.

Table 47: Redistribution of Contract Work Costs to Crop Groups in Results R0 to R4

	Crop Group*:			
Result	**Allgr**	**Allar**	**Scnd**	**Third**
R0	Yes	Yes		
R1	No	No	--	--
R2	Yes	No	--	--
R3	---	---	Yes	--
R4	---	---	Yes	Yes

**allgr: all crops of grassland, allar: all crops of arable land, scnd: all crops of second priority, third; all crops of third priority.*

For better understanding, the procedure is illustrated at two imaginary farms. A 'Farm 1' grows arable crops on 42 ha, but does not have grassland. It cultivates wheat, rape, and clover. These crops can be attributed to the crop groups: wheat, rape, and clover to 'allar'; wheat and rape to '4th priority' (compare Table 44). 'Farm 1' stated contract work costs of 3,550 € in FADN. 'Farm 2' grows arable and grassland crops on 25 ha. The farm cultivates cereals, silage maize, and grassland. The cereals are in one crop group, silage maize is one group, and grassland in another. 'Farm 2' stated contract work costs of 5,000 € in FADN. The parameters of both farms are summarised in Table 48 where the keeping of the lower and upper bound (low=y/n; up= y/n) is shown in the column of checking priorities 'Priority'.

At the first priority, it is checked if the stated costs could stem from all arable crops. On 'Farm 1' the FADN costs of 3,550 € are below the respective lower bound of 3,808 € (*1st, low=n*). Thus the second priority crops, here wheat and rape, are checked. The stated 3,550 € fall in between the respective bounds of 2,688 € and 4,608 € (*2nd, low=y and up=y*). For 'Farm 2' the FADN costs of 5,000 € are high enough to potentially originate from outsourcing the harvest work for 'all crops': the bounds of 'all crops' are kept (low=3,990 and up=6,840). Since the FADN costs of 5,000 € do not violate the bounds of grassland (low=3,150 and up=5,400), these costs could originate also from grassland only. However, the costs are redistributed to 'all crops' since the checking priority of 'all crops' is higher than of 'all grassland'.

On 'Farm 1' costs are redistributed to wheat and rapeseed. This is according to CRP_REL. CRP_REL_{wheat}= (111×20)/ (111×20+135×12) = 0.578, and $CRP\_REL_{rapeseed}$= (135×12)/ (111×20+135+12) = 0.422. The FADN costs of 3,550 € are redistributed with 2,051.90 € to wheat (3,550×0.578) and with 1,498.10 € to rapeseed (3,550×0.422). On 'Farm 2' the costs of 5,000 € are redistributed with

3,947.37 € to grassland and with 1,052.63 € to silage maize (5,000× CRP_REL_{grass}=0.789, CRP_REL_{smaize}=0.211).

Table 48: Redistribution of Stated Contract Work Costs (Example)

Nº	Title	Farm Area	Default Cost	Lower Bound	Upper Bound	Priority			Result
						1ST	2ND	3RD	
		(ha)	(€/ha)	(€)	(€)				(€)
Farm 1: FADN Contract Work Costs: 3,550 €, UAA: 42 ha									
1	allar: wheat rape clover	 20 12 10	 111 135 160	3,808	6,528	low=n up=y			
2	wheat rape	20 12	111 135	2,688	4,608		low=y up=y		2,052 1,498
Farm 2: FADN Contract Work Costs: 5,000 €, UAA: 25 ha									
1	all crops	20 5	225 240	3,990	6,840	low=y up=y			3,947 1,053
2	all grass	20	225	3,150	5,400		low=y up=y		
3	silage maize	5	240	840	1,440			low=y up=n	

3.4.3.6 FADN Cost Item 6: Wages Paid

The wages paid according to the FADN data set are not considered. Although the influence on total variable costs can be striking, the redistribution is too sensitive. In contrast to the redistribution of stated contract work cost, no general rules or any scheme in the farmers' decisions on hiring (paid) workers could be identified that would allow for the redistribution of the stated wages paid. Additionally, distortions from farms with a high share of labour intensive production (e.g. specialised crops) would be uncontrollable.

An exemption is the sorting and storage of food potatoes. Harvest and post harvest works are so labour intensive, but at the same time only periodic, that only very few farms would be able to perform this work without additional hired workers. Since wages paid for food potato production will often only be a share of the stated FADN stated wages, an alternative wage was calculated. Country specific statistics on the area of food potato cultivation and average national wages paid for sorting were intersected. This average value was then added on a pro-rata basis to the unspecified costs of potato production in general.

3.4.3.7 FADN Cost Item 7: Interest on Circulating Capital

Based on the redistribution of FADN Cost Items 1 to 6 it can be summarised that some cost items are based on the stated FADN costs and some are based on alternative cost estimates. Because of this ambivalence of values and the problems of distortions (for example from special crops included in the FADN cost values), it seems most appropriate also not to base the "Interest on Circulating Capital" on the stated FADN costs, but on an alternative value.

Consecutively to the redistribution of FADN Cost Items 1 to 6, the interest on circulating capital is added to all those assets that represent circulating assets. The following are considered circulating assets: plant protective agents, seeds, and fuel (fertiliser is excluded since it is determined model endogenously). On these assets a six percent interest rate is charged during an assumed average capital commitment phase of six months. The interest rate approximately corresponds to average interest rates on long-and short-term loans (KTBL, 2004). The capital commitment phase seems reasonable for the conditions in the EU-15 and corresponds to the period between sowing and harvesting, i.e. between capital investment and capital backflow. It is also the procedure proposed by REISCH and ZEDDIES (1992), who calculate the interest for 50% of the purchase value since normally capital is committed for 50% of the investment period.

3.4.3.8 Summary

In FADN cost are indicated per cost item and no deeper splitting is available. This splitting was maintained in the introduced approach and is listed in Table 49 where the calculation method in the approach is assigned to each cost item. From the table it can be retraced whether either the standard CRP_REL or an alternative calculation method is drawn. CRP_REL is directly deduced from the FADN cost data, while the alternative methods draw on literature or are directly simulated in the model and the necessity for an estimate spares.

Table 49: Structural Summary: Estimating Plant Production Costs

Item N°	Cost Item	Subcategory	Procedure
1	Factor Costs	seeds pesticide fertilizer	country specific source CRP_REL model endogenous
2	Maintenance	---	CRP_REL
3	Fuel	---	CRP_REL
4	Electricity	---	KTBL
5	Contract Work	---	CRP_REL
6	Wages Paid	---	CRP_REL
7	Interest	---	6% on circulating capital

3.4.4 Extreme Values

Solving EU-EFEM the optimal organisation and maximal gross margin is iterated for region typical farms and not for real farms. The reference to these region typical farms is the reason why the farm specific results from the described approach for the deduction of crop production costs cannot be directly copied, but have to be regionalised. The regionalised values then can be applied to any farm within the same region. The regionalisation is achieved by drawing a regional average value. The average is only for farms of the type “arable crop”, “forage growing”, “intensive livestock”, and “mixed farms”. “Horticultural farms” and “permanent crop farms” are disregarded in EU-EFEM and so they are disregarded in the cost estimate, as well. Further, in regionalisation the only farms that are considered in the FADN are those that keep the following criteria:

a) The sum of arable land and grassland has to represent at least 95% of the total farm area, and

b) The Gauss-Standard distribution explains the deviation from the regional mean value.

The main objective for the application of criterion a) is to filter out farms with a high share of special and/or permanent crops like orchards or forests. These cultures bias the result featuring relatively high expenditures for contract work or wages. Fostering orchards, cleaning forests or cutting wood are all labour intensive processes. This bias is also assumed to be the reason for the occurrence of the result ‘R1’. In ‘R1’ the upper bounds for all grassland and arable crops together could not be kept, i.e. the FADN costs exceeded the upper bound of the expected costs, so that finally FADN costs were not redistributed to crops. Against this background, with criterion a) farms that cultivate these special and/or permanent crops in excess of 5% of the total farm area are excluded from the analysis. However, in this criterion a certain bias cannot be avoided in its whole, since already marginal shares of special and/or permanent crops can cause contract work costs to rise substantially and bias contract work costs assigned to grassland and arable crops.

The result of the current approach for estimating contract work costs is the stated FADN contract work costs redistributed to the grown crops for farms surveyed for the FADN dataset. The found cost values are expected to be normally distributed around the mean value i.e. Gauss standard distribution. With criterion b) it is hypothesised that the Gauss standard distribution explains the deviation of the production costs of farms from the regional mean value. In the Gauss standard distribution, a confidence interval of 95% corresponds to ±2 standard deviations from the mean value. Cost estimates deviating more than 2 standard deviations from the mean value were thus filtered out. In drawing the regional mean value the farms with grassland in excess of 95% of the UAA or with more than 45% of the UAA being grown with a single crop experienced a double weighting. The reasoning is that in such cases the probability that stated FADN contract work costs stem only from grassland or this single crop is larger than average.

3.4.5 Special Cost Item: Irrigation

Irrigation is only assumed to occur in sugar beet and rice production. Based on FADN data, irrigation of sugar beet is assumed to occur in three Spanish and also in three Greek regions[55]. Costs of irrigation in sugar beet are uniformly assumed to be 200 €/ha. All rice produced in the EU is irrigated according to FERRERO (2006). For 80% of the farmers he assumed costs of up to 250 €/ha, and for 20% costs of up to 80 €/ha. The second group reduces costs by applying their own spring water. For this study an average cost of 216 €/ha is presumed.

3.4.6 Crop Production Costs under Alternative Management

The approach for estimating plant production costs in conventional tillage system cannot be conveyed to conservational tillage. One of the two main entries, the FADN farm accountancy data, does not discriminate costs of conventional tillage from costs of conservational tillage. That is why it had to be assumed all costs indicated in the

---

[55] Greece: Anatoliki Makedonia, Kentriki Makedonia, and Thessalia. Spain: La Rioja, Castilla y León, and Castilla-La Mancha.

accountancy data were from conventionally tilled crops. Although theoretically possible, the arguments against the sole use of KTBL engineering cost data, i.e. regional validity restricted to Germany, in first place, persist.

Instead, it was preferred to rely on the generated results for conventionally tilled crops and to intersect these values with engineering cost data only as far as is the difference between conventional and conservational tillage according to the engineering cost approach. This procedure is justified since the German KTBL defines costs per field activity and these can be attributed to either conventional or conservational tillage.

In so doing, for conventional tillage and the conservational tillage schemes, namely mulch seeding and no-till, the typical field trips and field activities has to be defined. The definition is according to KTBL and under the *ceteribus paribus* condition, i.e. field plot sizes or machinery performance levels are the same for the compared schemes.

Table 50: Conservational Compared to Conventional Soil Management

	Root Crops		**Cereals and Oilseeds**	
Item	**Mulch**	**No-till**	**Mulch**	**No-till**
machinery (№ of trips)				
ploughing	-1	-1	-1	-1
sowing		-1	-1	-1
field tiller		-1		-2
chisel plough	+1		+1	
rotary harrow	+1		-2	-1
combined rotary harrow	-2	-2	+1	
driller Sowing Combination	+1		+1	
herbicide spraying		+1		+1
direct sowing		+1		+1
straw chopping accessory		+1		+1
others (percentage)				
herbicides and pesticides	+15%	+30%	+10%	+30%

The change in the number of field trips and in the application quantities of pesticides is illustrated in Table 50. Ploughing is made redundant in conservational tillage and replaced by the soil disturbing chisel plough and rotary harrow in mulch seeding. Furthermore, the seeding technology is changed from conventional machines to combined sowing machines which open the soil for the seeds and cut surface litter into pieces. For the reduced decomposition rates of organic material in conservational tillage (litter is not mixed with the soil), which is a major determinant for the diffusion of pests, herbicide application amounts are assumed. Herbicide application rates are increased by 10% for mulch seeding and by 30% for no-till. These additional amounts are justified under German average conditions, regardless of the high variation caused by climatic, soil and weather variability, although, in any case, higher herbicide amounts will not really be necessary (BRAND-SASSEN, 2004). Because of this negative impact of exuberant surface litter on pests and also on field emergence it is assumed that under conservational tillage straw was chopped with a special accessory device attached to the combine harvester. By intensified chopping a faster straw degradation is initialised.

The difference between conventional tilled and other crops is then calculated as the product of the number of field activities times specific activity's costs. The obtained value is country specific, like the definition of default KTBL costs with its country specific parameters (fuel price, etc.). A region specific adoption (EU-EFEM regions) of the obtained value is only appended afterwards. This adoption reflects the deviation between the estimated and the expected costs of a certain conventionally tilled crop, i.e. between the result of the presented approach for conventional crops and the KTBL engineering value. This means assuming the difference between the expected value and the declared costs was the same in conventional and conservational tillage systems.[56]

With the example in Table 51, it can be retraced how region specific production costs of conventional tillage flow into the estimate of region specific costs for conservational tillage. In row 9, the costs of the crop (here wheat) under conventional tillage are added a region and crop specific value (from row 7). This region specific value is deduced from the difference between KTBL costs of conventional and conservational tillage ("Δ-costs default", row 1). The KTBL costs, which are default values, are the same for all cereals and are not wheat specific. KTBL bases its cost values on a diesel price of 0.48 €/l. The KTBL costs are then corrected for the actual and country specific diesel price (see row 4). From this exercise, the country specific cost differences between conventional and conservational tillage are obtained (row 5). This country value, that so far is only specific to cereals, is finally adopted by

---

[56] Only deviations of up to 100 % are obeyed, i.e. the coefficients 2.0 and 0.5 represent extreme values.

the region and wheat specific relation between the calculated FADN costs (of conventional wheat) and the expected KTBL costs (of conventional wheat) (row 6).

Table 51: From Plant Production Costs in Conventional to Conservational Tillage (Example)

Row	Row Title	Action	Crop Reference	Costs (€/ha)	
Country Specific Values				**Country 1**	**Country 2**
Default KTBL:					
1	Δ-costs default		cereals	-17.55	-17.55
1a	whereof diesel		cereals	-6.00	-6.00
Country Adoption:					
2	KTBL diesel price		---	0.48	0.48
3	Actual diesel price		---	0.71	0.39
4	Diesel price correction	1a×(3-2)	---	-1.38	0.53
5	Δ-costs country specific	1+4	---	-18.93	-17.02
Region Specific Values				**Region 1**	**Region 2**
Regional Adoption					
6	Relation FADN/KTBL		wheat	1.20	1.05
7	Δ-costs region specific	5×6	wheat	-22.72	-17.87
Results					
8	Conventional tillage		wheat	613.20	498.00
9	**Conservational Tillage**	7+8	**wheat**	**590.48**	**480.13**

Labour, as an important production factor, plays a major role in any production cost estimate. Depending on the scarcity of labour on a farm, the specific opportunity costs affect the economic excellence of conservational tillage vastly since, in general, conservational tillage is less labour intensive. In most cereals around 0.6 h for mulch seeding and around 2.2 h are saved per hectare, while for maize the figures are 0.0 h and 1.8 h. Determining the scarcity of labour at a certain period is difficult even if the concrete labour endowment of a farm could be known (compare previous section).

3.4.7 Results for Plant Production Costs

The results of the above described approaches for estimating crop production costs under conventional and conservational tillage will be shown in the following. It is to be remembered that at this point the costs of fertilisations are only considered for fertiliser spreading but not for the fertiliser itself. The costs of the applied fertiliser are calculated model internally.

3.4.7.1 Results for Crops under Conventional Tillage

The approach for estimating production costs of crops under conventional tillage maintains the division into FADN cost items during the assignment of costs according to accountancy values. The results' presentation thus allows for depicting the estimated cost values per FADN cost item. This is done in Table 52 (the cost item "interest on circulating capital" is included under "Machinery"). The table shows the values of the randomly chosen South-German region Stuttgart. Analysing the table, one might fall on the relatively low estimate for "Fuel" of potatoes, sugar beet, and silage maize. This phenomenon is explained by the simultaneous relatively high expenditures for contract work and the substitute relationship between fuel and contract work expenditures. The phenomenon occurs in all analysed regions. The production costs for grass silage are always to be seen in relation to the number of cuts, in this case four.

Table 52: EU-EFEM Cost Estimate for Conventionally Tilled Crops (Example Stuttgart)

Crop	**Machinery**	**Fuel**	**Seeds**	**Pest Control**	**Contract Work**	**Electricity**	**Total**
				(€/ha rounded)			
winter wheat	131.9	134.7	72.0	132.1	109.7	9.3	**589.80**
spring wheat	125.3	128.0	68.4	125.5	104.2	8.8	**560.30**
rye	173.6	144.9	69.0	98.7	92.0	8.4	**586.50**
winter barley	132.1	129.2	60.0	111.7	109.2	7.8	**550.00**
oats	127.5	121.7	43.0	40.2	104.7	7.6	**444.60**
spring barley	122.9	120.2	55.8	103.9	101.5	7.3	**511.50**
grain maize	243.0	227.8	165.0	103.4	148.3	34.8	**922.40**
field pea	149.1	106.8	108.0	62.2	124.6	5.2	**555.80**
potato	249.2	70.8	496.0	190.7	294.7		**1,301.30**
sugar beet	155.0	101.6	233.0	248.0	297.5		**1,035.00**
rapeseed	134.1	126.4	43.0	145.5	136.5	5.8	**591.40**
silage maize	110.0	92.1	140.0	80.6	218.3		**641.10**
green clover	75.6	71.9	74.0		59.6		**281.10**
grass silage[57]	157.5	89.7			85.3		**332.50**

Because of their high number the estimates for the rest of the EU-15 are presented in GIS-maps where, because of illustrative reasons, only classified results are depicted. The classification criterion is "equal class size", i.e. in each class the same number of regions is represented. Relatively narrow class borders hint at similar costs for the regions contained in the same class, while wide borders hint at

---

[57] Without storage costs (these are accounted for later on in the model).

high class internal cost diversity. The presentation in GIS-maps should grant the reader fast access to the results.

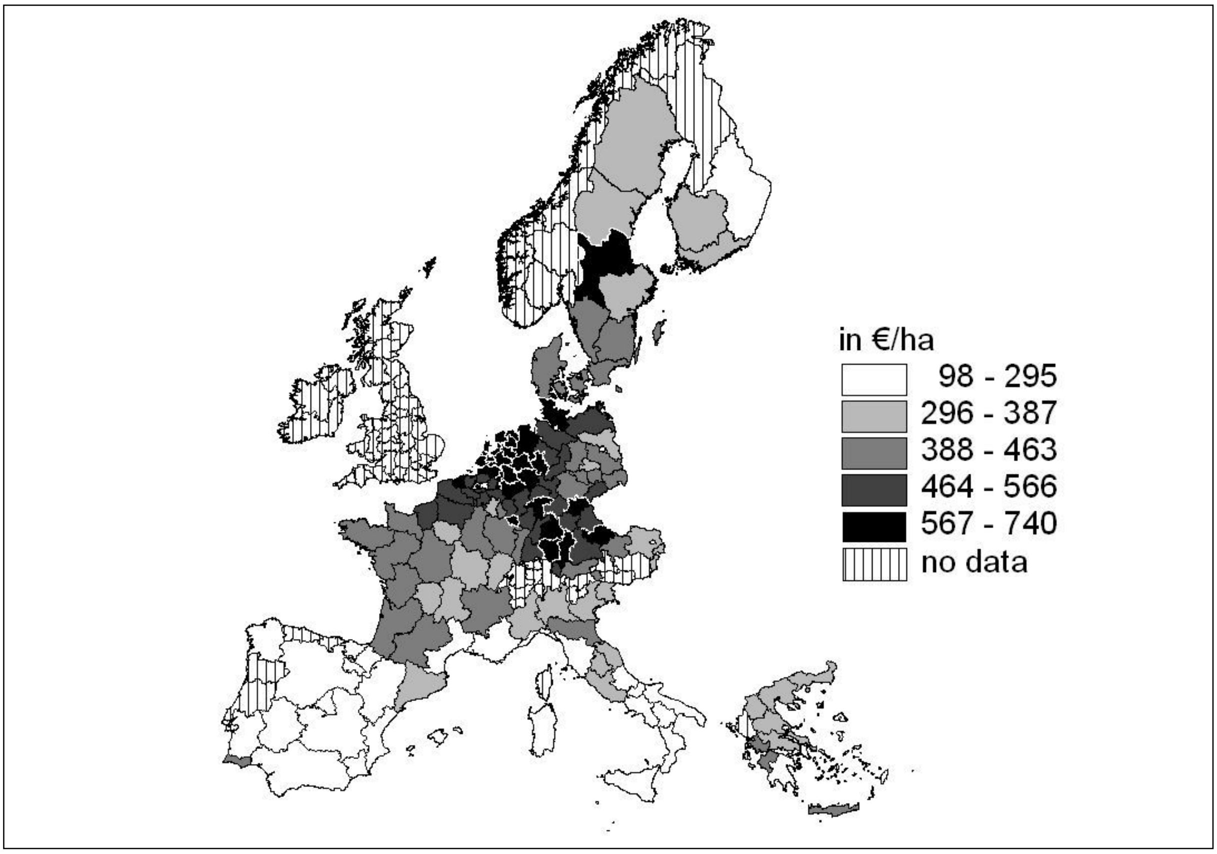


Figure 5: Variable Costs for Winter Wheat (excl. fertiliser)

Figure 5 shows the production costs for winter wheat. The costs are divided in 6 classes, including the class 'no data' for regions where the FADN accountancy data stated zero cultivation of winter wheat. In the model this gap will be bridged by an EU-15 average value instead. As stated above, a narrow class border means that the regions within that border show similar costs. The narrowest borders are in the third class with 75 €/ha (463 - 388). Also the second and the forth show narrow borders. The borders are wider in the fifth and in the first class with 173 €/ha (740 - 567) respective 197 €/ha (295 - 98). Without weighting the regions, the average costs are 425 €/ha.

Figure 6 shows the production costs for sugar beet. The variety of values is not as large as for winter wheat. The third class shows significantly narrower borders than the other classes and so costs concentrate between 861 and 900 €/ha. The large number of regions with 'no data' is because sugar production in the EU and the EU-15 is concentrated in some major production zones.

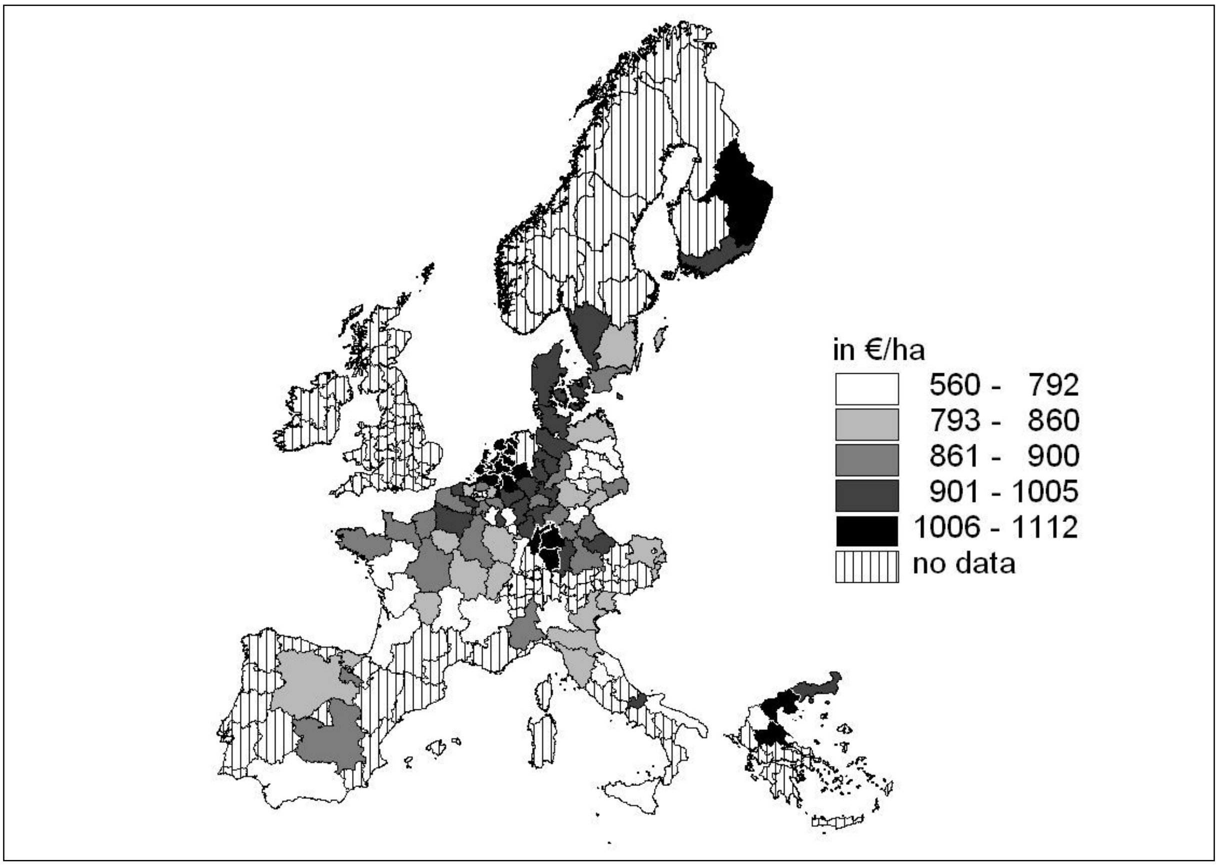


Figure 6: Variable Costs for Sugar Beet (excl. fertiliser)

Analysing the presented results for winter wheat but especially for sugar beet one might be misguided. A different picture might have been expected since especially the central European cereal regions seem to be dominated by adverse high costs while southern European regions show low production costs. However, high costs often fall together with high yields and intensive production. Following this idea, gross margins should be highest in the central European regions.

For winter wheat, highest gross margins coincide with the main cereal production zones. Gross margins are highest in the North of France and the North and North-East of Germany (see Figure 7). The lowest gross margins are achieved in Swedish and southern European regions with values below 90 €/ha or even negative values up to -308 €/ha. If the subsidies were included the picture might be different. If still negative, production might be justified by crop rotational reasons.

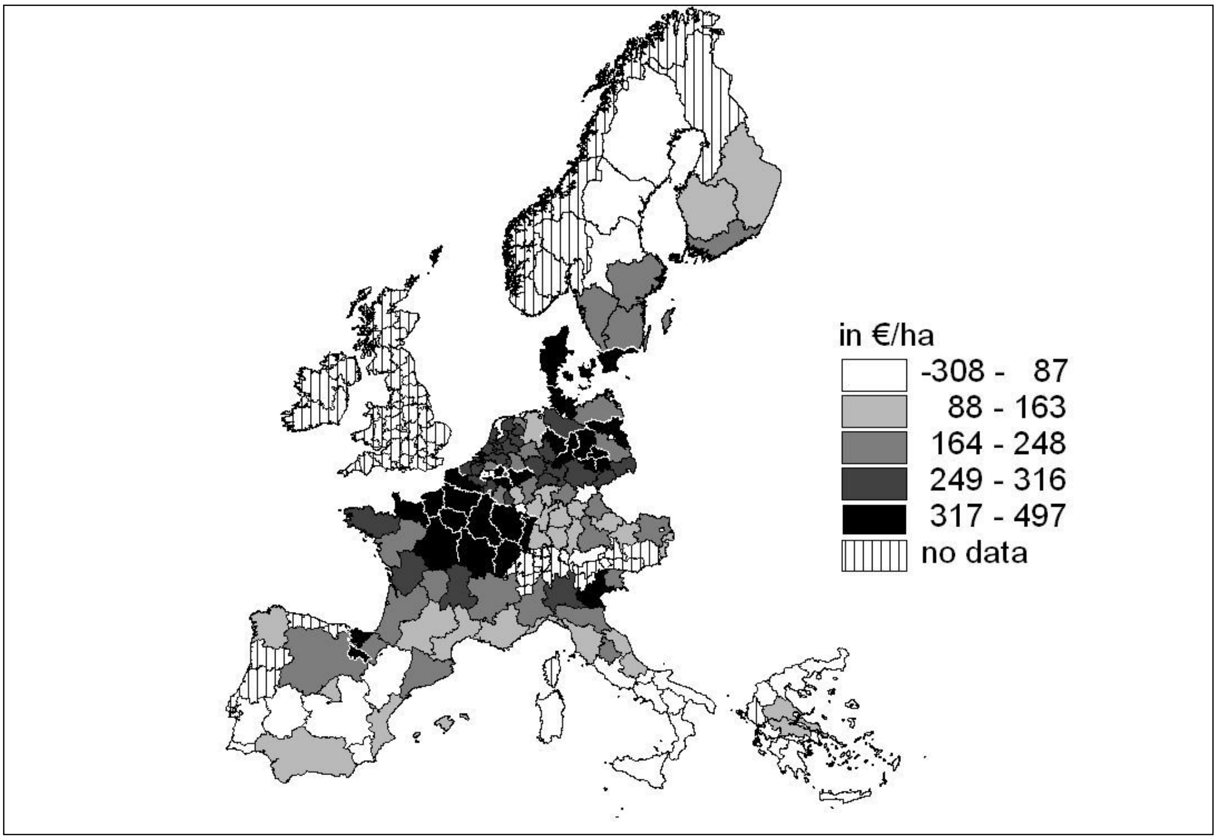


Figure 7: GM for Winter Wheat (excl. subsidies and fertiliser)

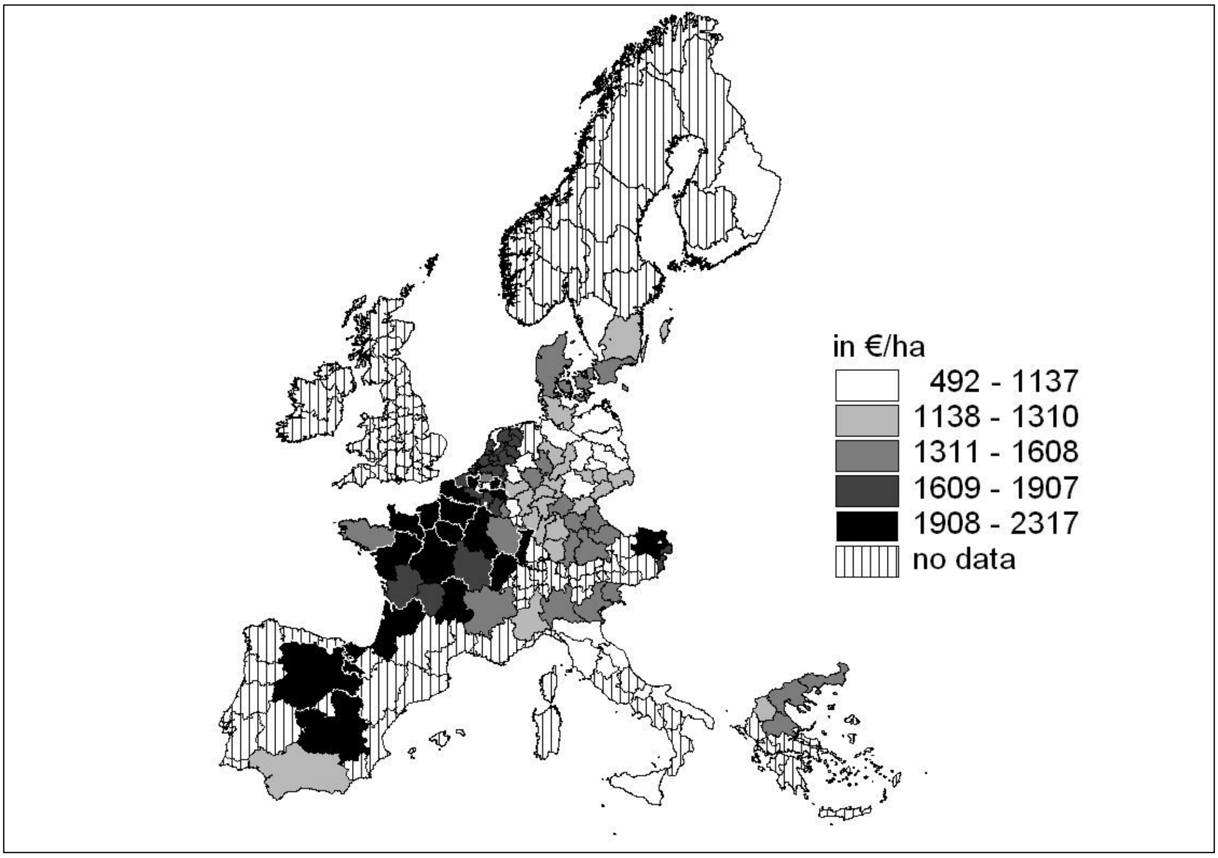


Figure 8: GM for Sugar Beet (excl. subsidies and fertiliser)

Sugar beet gross margins are highest in Northern and Western France and in Central Spain (Figure 8). Spain features extraordinarily high sugar beet yields due to irrigation and comparatively high beet sales prices. Sales prices in Spain were indicated at approx. 50 €/t of beet for 2000 to 2002 (in Germany, a major beet producer in Europe, only 41 €/t). Partially the relatively low estimate of irrigation costs (it was uniformly assumed at 200 €/ha) might contribute to the high local competitiveness.

3.4.7.2 Results for Crops under Conservational Tillage

The approach for calculating the production costs of crops under conservational tillage is not the same as for conventional tilled crops. The approach calculates the cost difference to conventional tillage. That is why only this difference shall be shown here. In order to reflect the entire decision for or against conservational tillage, the difference gross margins shall also be shown. In this the yield impact is included, as well. With respect to the yield impacts two extremes will be mentioned here: either all or no residues are withdrawn from the field.

Table 53 shows the change of the production costs if a switch is made from conventional to conservational tillage (represented by mulch seeding and no-till). The indicated value is the mean over all study regions in the EU-15. In contrast to the average value, the mean is not weighted according to the represented area. It can be seen that on this mean level costs are lower for almost all crops than under conventional tillage. This applies to both, mulch seeding and no-till. Only for two crops, potato and sugar beet, costs are higher. For grain and silage maize, costs of mulch seeding are lower with conventional tillage but higher with no-till. The cost reduction can be substantial. In oats and sunflower, switching to no-till reduces costs on a mean level by more than 35 €/ha. For potato, in contrast, the costs are more than 60 €/ha higher under no-till.

Table 53: Change of Costs Switching to Conservational Tillage (EU-15 Mean)

Crop	Mulch Seeding	No Till	Crop	Mulch Seeding	No Till
	(€/ha)			(€/ha)	
field pea	-5.61	-21.56	spring barley	-9.61	-29.21
Oats	-11.64	-35.30	silage maize	2.96	-7.56
potato	29.32	61.04	spring wheat	-8.51	-25.90
green clover	-7.73	-14.15	winter barley	-9.07	-27.60
grain maize	5.19	-16.47	rapeseed	-11.26	-22.72
Rye	-9.37	-28.50	winter wheat	-8.12	-24.74
sunflower	-4.73	-37.82	sugar beet	10.57	22.00

In summarising the cost effect, it can be stated that on EU-15 mean level, costs of conservational tillage are lower than of conventional tillage with only a few, but significant, exemptions. Considering at the same time the yield impact, the mostly positive cost effect might be eaten up. The yield impact and the costs are both implied in the gross margin.

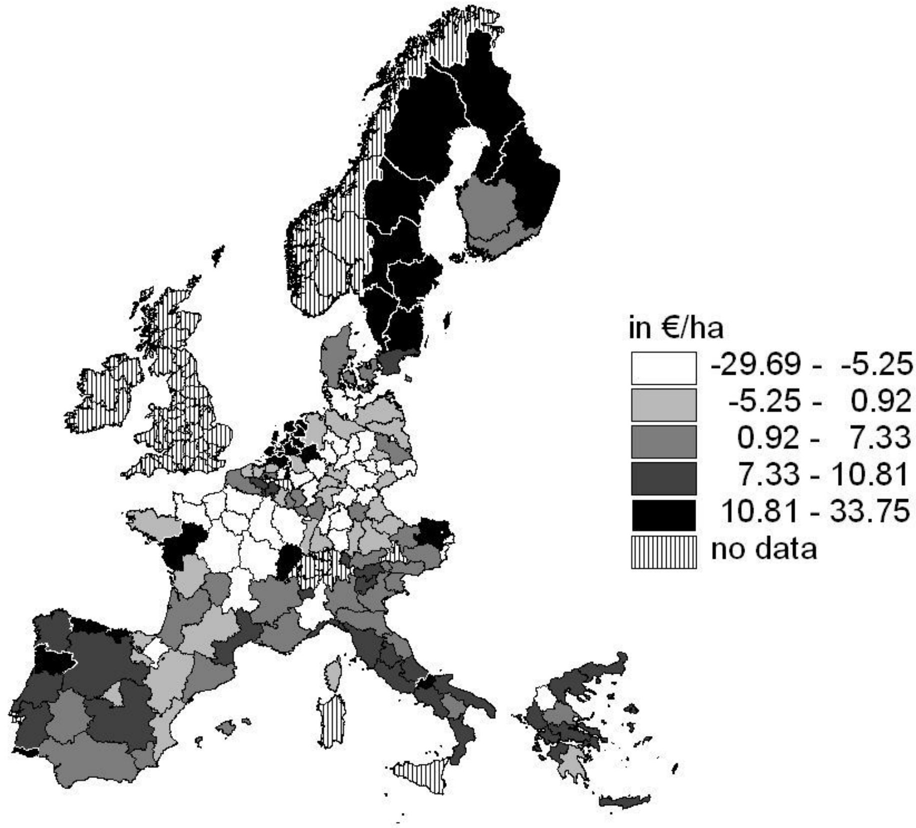


Figure 9: Change of GM from Conventional to Mulch Seeding for Winter Wheat (100% Straw Withdrawal)

In Figure 9 the economic effects of switching to mulch seeding in combination with withdrawing all straw for winter wheat is depicted. Since equal size classes are the classification criteria for the GIS-maps, the mean region is included in the centre class, i.e. in the third class. This one shows a positive impact on the gross margin, ranging from 0.92 to 7.33 €/ha. It means that in general it pays to switch to mulch seeding. But especially in German and French regions, the impact on the gross margin is negative, with a decrease of up to -29.69 €/ha. The German and French regions which are relatively heavily affected lie in the major cereal production zone of the EU-15.

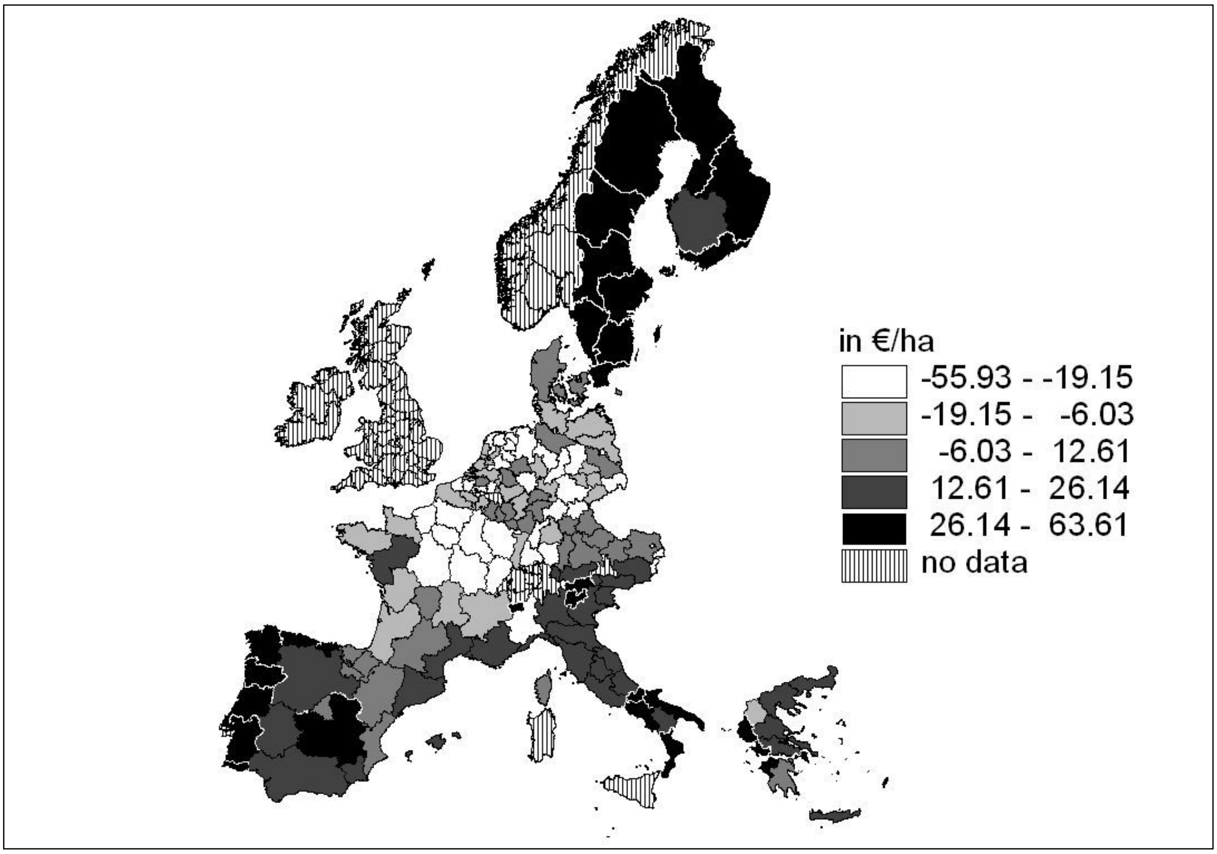


Figure 10: Change of GM from Conventional to No-till for Winter Wheat (100% Straw Withdrawal)

In Figure 10 the economic effects of switching to no-till in combination with withdrawing all straw for winter wheat is depicted. The situation is pretty much the same as for mulch seeding. The highest negative change of the gross margin is again in German and French regions. But the impact is more extreme since now nearly all German and French regions are negatively impacted. In all other countries farms benefit from switching the tillage management.

It has already been shown that on an average level and with restricted validity, crops like grain maize, potato, sugar beet, sunflower, and rye react with large yield decreases if the management is switched to conservational tillage in combination with 0% straw withdrawal from the fields. That the change of the gross margin can be a lot worse for farmers than for winter wheat shall be shown at the example of grain maize (Figure 11). There it can be seen that in this case in all regions the gross margin is negatively affected with only a few exemptions. The change in the gross margin can be as high as -180.75 €/ha.

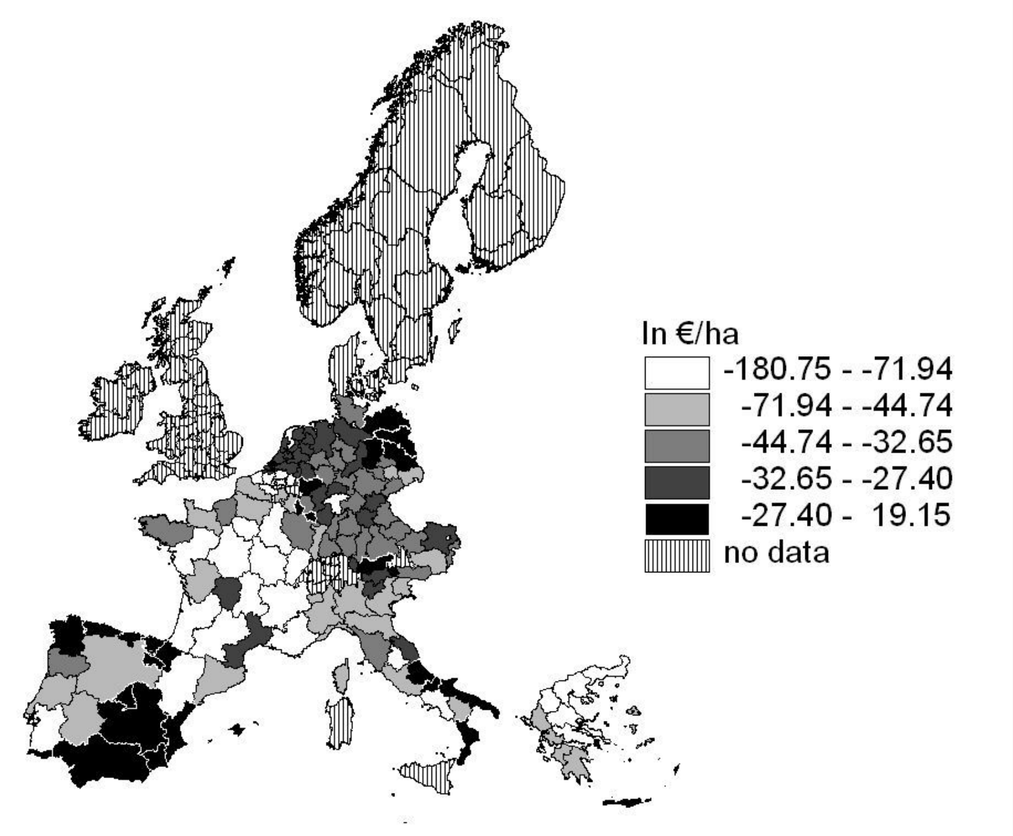


Figure 11: Change of Profit from Conventional to No-till for Grain Maize (0% Straw Withdrawal)

Although for grain maize conservational tillage reduces production costs by 16.47 €/ha on EU-15 mean level (compare Table 53), the reduction of the gross margin can be as high as -180.75 €/ha. The monetised yield impact thus can take significant dimensions, especially in the case of 0% straw withdrawal. In order to give an idea of the dimensions for all crops, the (again unweighted) EU-mean value of the change of gross margin is shown in Table 54. The extremely high reductions of the gross margin of sugar beet are striking. On a mean level the change in the GM is -888.95 €/ha for mulch seeding and reaches -2,174.14 €/ha for no-till. Also for potato a large loss is faced if switching to conservational tillage. The potential gains are far more moderate and even the maximal change of GM on EU-mean level is only 21.77 €/ha, achieved for oats.

Table 54: Change of GM Switching to Conservational Tillage: EU-Mean (0% Straw Withdrawal)

Crop	Mulch Seeding	No Till	Crop	Mulch Seeding	No Till
field pea	-4.37	13.38	spring barley	5.61	17.08
Oats	4.51	21.77	silage maize	-2.47	9.97
Potato	-111.37	-334.45	spring wheat	5.39	10.71
green clover	8.05	14.71	winter barley	1.89	9.87
grain maize	-28.06	-49.47	rapeseed	1.34	4.65
Rye	-6.32	7.03	winter wheat	-1.79	1.43
sunflower	-15.86	4.52	sugar beet	-888.95	-2,174.14

3.4.8 Critical Remarks on Estimated Plant Production Costs

The presented approaches for estimating production costs of crops deduce costs separately for each cost item in the FADN accountancy dataset with the aim to generate cost data for crops cultivated by the simulated farms in a European NUTS-II region. Since the simulated farms are non-existing but only imaginary, it is not feasible to approaching the cost with accountancy data of the simulated farms.

Among the FADN cost items on which the estimate is based the item “contract work” was the most critical one. First, this is owing to the relative importance of contract work with respect to total variable costs. Second, contract work costs do not occur for all crops, leaving the question for correct assignment to single crops. Third, default contract work costs are lacking in the engineering cost database used. It may be supposed that contract work costs depend very much on farm labour endowment, seasonal labour peaks, machinery equipment, and actual weather, all together factors which show a wide variation among farms, making determination with default values too vague and inaccurate.

Only by simulating labour endowment, seasonal labour peaks, actual weather and seasonal labour requirements for the simulated farms, a determinant to which contract work expenditures could be relied on as fixed could be created. In the concrete case, the simulation of all this factors is expensive and a difficult task. Finally, although uncertainties remain about the correct assignment of “contract work” expenditures to crops, no better mode than the one taken could be conceived.

A disadvantage to the presented approach is that it merely considers the cost side of an investment and neglects the revenue side. Within the model the revenue of a certain crop is only influenced by production intensity expressed in fertilisation quantities and tillage management. Other factors like storekeeping to make use of price fluctuations are not available to the farms. That means that such investments may only entail higher variable costs, if any, which are not compensated for by higher revenues. The unknown endowment of farms with production factors (e.g. storage silos) aggravates the assignment of FADN expenditure to crops.

Due to the lack of any comprehensive estimate of production cost data in the EU-15 on regional level, the results generated are assumed to attribute a considerable value to the approach taken in this study. However, this lack of data also aggravates validation. The CAPRI model, for example, simulating EU agriculture also on NUTS-II level, mentions to utilize the Standard Gross Margins (SGMs) available through the FADN, but to supplement this by the Gross Value Added (GVA) calculation and quadratic cost functions (CAPRI, 2010). Through the FADN, SGMs for more than 90 crops and animal products should be available on regional level. The FACEPA study financed by the Seventh Framework Program of the European Commission, searches ways to utilize FADN data to deduce production costs (variable and/or fixed) (FACEPA, 2008).

Only the expected cost according to KTBL shall be compared to the result, the estimated cost according to the presented approach. As already has been mentioned the KTBL does not define a certain cost value, but it gives a range in which costs can be modified according to factors like field sizes, utilized machinery, and so forth. In Table 55 this comparison is made on the targeted regional level of NUTS-II-regions for some selected crops and illustrated at the example of Germany, where KTBL values stem from and are thus supposedly the most adequate ones. In this example the maximal deviations are -44%, which is found in sugar beet and +28% which is found in grain maize. Both crops show in the KTBL also a very wide range of potential cost values, so that this deviations could be explained by KTBL alone, also. A principal reason for the deviation from the assumed average KTBL costs is probably mainly due to the average inclusion of the significant cost factor “contract work”.

Table 55: Deviation '*Expected Cost (KTBL)*' to '*Estimated Cost (Approach)*': Example Germany

	Crop					Crop			
REG	**Wheat**	**Maize**	**Potato**	**Beet**	**REG**	**Wheat**	**Maize**	**Potato**	**Beet**
		(%)					(%)		
de11	112	119	94	105	de93	103		96	94
de12	105	97	91	101	de94	102	108	105	95
de13	97	**128**	90		dea1	118	110	112	113
de14	109	98	93	115	dea2	99	110	87	99
de21	95	85	85	87	dea3	109	111	104	108
de22	113	106	97	99	dea4	104	114	104	88
de23	93	95	87	90	dea5	107	86	80	90
de24	118		105	115	deb1	91		75	85
de25	103	100	90	90	deb2	92		52	**56**
de26	96	100	86	90	deb3	99	96	92	101
de27	107	105	99	95	dec0	87		97	
de41	68	69	65	72	ded1	91	102	85	85
de42	76	71	88	71	ded2	83	65	85	84
de71	101	104	86	92	ded3	79	88	70	77
de72	93	94	86	85	dee1	80	77	75	75
de73	93		88	94	dee2	76	62	78	74
de80	92		82	84	dee3	75	54	71	75
de91	98		113	86	def0	104	104	100	89
de92	95	88	91	92	deg0	84	89	81	81

3.5 Animal Production Costs

This section treats the deduction of costs in animal production. In contrast to plant production, the problem is settled differently since the degree of product uniformity is by far lower. Whilst in plant production, cultivated winter wheat always yields winter wheat; cattle can be placed on the market in the form of many products with different sales prices per unit. Because of this particularity, it is not possible to estimate production costs in the same way as for plant production. In place of the combined approach taken in plant production, combining accountancy and engineering approach, here a pure engineering approach must be relied upon.

Costs of animal production are composed of expenditures for veterinary services, mineral feedstuff, water, electricity, and interest on circulating assets. In Table 56 the values used in EU-EFEM are presented. They are uniform for all study regions. The item "veterinary and other services" includes all other items apart from mineral feedstuff, water, and electricity. It includes interest on circulating capital, marketing costs, and so on. In the case of dairy cows "electricity" also includes the costs for milking (incl. cleaning water etc.).

Table 56: Costs in Animal Production according to Cost Item

Animal Type	Veterinary and Other Services	Mineral Feedstuff	Water	Electricity	Followers
		(€/head/year)			
fattening calf		- included in "suckler cow" -			intern
baby beef	100.0	25.0	25.0	1.4	intern
breeding heifer	125.0	20.0	20.0	2.0	intern
fattening heifer	182.0	25.0	27.0	1.4	intern
breeding bull	45.0	20.0	25.0	2.0	intern
fattening bull	182.0	29.0	27.0	1.4	intern
piglet	15.9	63.4	0.3	2.4	intern
fattening sow	36.0		0.8	8.2	intern
breeding sow	132.0				intern
dairy cow	120.0 - 220.0	31.5 - 69.3	62.5 - 95.0	135.5	intern
suckler cow	85.0	18.9	50.0	3.0	intern
breeding sow	204.0				intern
sheep	76.0				bought
laying hen	13.8				bought
other poultry	7.2				bought

The production of followers is a singular production activity, directly linked to the production activity of an adult animal. Costs for the production of followers are accounted for. Only for sheep and poultry no separate production activity is formulated in EU-EFEM, but followers are directly included with their purchase price in the production activity of the adult sheep and poultry (in Table 56 included in "veterinary services").

Because of the production of followers for cattle and pigs, so called demography-variables were introduced, variables that account for the different needs at different ages of the animal. In case farm capacities of stable places do not suffice to bring up all the followers necessary to keeping adult animals, then followers can also be bought on the market at a price slightly above production cost (in order to avoid substitution effects in the model).

From the costs indicated per year and per head in the table above, or in other words the costs per stable place, the costs per animal are deduced by intersection with the keeping duration of an animal. To the keeping duration is added a two-weekly stable vacancy for disinfection for all categories of pigs. For example, 5.9 production cycles per year for piglets are assumed. The costs per stable place are 82.0 € (see Table 56). So the costs per piglet amount to 13.9 €/piglet (82 €/stable place divided by 5.9 piglets/stable place).

3.6 Labour

Also labour is calculated activity based in the model. Thereby default values of labour requirement per activity are copied from KTBL (KTBL, 2004). The labour endowment of farms in Europe is indicated in the FADN accountancy data. The correctness of such data is however questioned by this study for two reasons. First, especially the indication of family members as work force or other casual assistance depends on the fiscal systems and the freedom of choice of the entrepreneur to indicate such work force. Second, the decimal accuracy of such an indication of part-time workers is doubted. A better data source on farm labour endowment does not exist, in contrast. So, in the model it is not treated restrictively and the purchase of manpower is allowed and of low costs. The number of unpaid labourers is assumed at 1.5/farm for farms up to 100 ha of UAA and at 2.3/farm for larger farms. In the model, a full labourer can perform up to 3000 h annually. Besides seasonal upper limits of labour performance are formulated and restrict the model.

3.7 Regional Coverage for Farm Type Model

The high degree of regional disaggregation of any farm type model is advantageous in regard to single farm analyses, but does not generate desirable regional coverage. Extrapolation represents a way out of the dilemma between generality and specification. The following steps are taken in order to bridge this gap:

1) Drawing average farms described by main production factors,
2) Identifying main regional capacities,
3) Constructing region typical farms,
4) Extrapolating region typical farms to depict selected regional capacities,
5) Calibrating region typical farms.

Finally, in EU-EFEM, calibrated region typical farms are simulated. These farms are artificial farms that are only deduced from real farms, yet capture the main characteristics of real farms. Modelling single selected real farms would have meant neglecting the variability among farms and neglecting some farm characteristics. This would have raised the question of representation.

3.7.1 Average Farms

Because of reasons of representation and capturing the entire variety of farms, EU-EFEM calls upon an average of farms, thus capturing the entire regional variety. The "average farms" are deduced from the FADN dataset of accountancy farms. The FADN farms are thereby averaged over a certain group of farms within the dataset. Along with this average calculation comes the disadvantage of changing original integer numbers to fractions and of levelling out extreme values. The first does not serve EU-EFEM's objective to deliver clearly interpretable and expressive results. Therefore, average farms only represent a first step to the farm units simulated in EU-EFEM.

The FADN dataset classifies farms according to three dimensions: 1) regional affiliation, 2) economic size class, and 3) farm type. For EU-EFEM it was decided to keep two dimensions and neglect one. With the regional affiliation and the farm type it is assumed that agricultural production is captured in sufficient detail. The economic size class is defined according to regional affiliation and as such is very diverse. Scenario reactions are not assumed to differ significantly between the size classes.

The regional affiliation in the FADN dataset is according to a FADN definition of regions. This definition does not intersect with the EU-EFEM definition of regions, which is the NUTS-II. Fortunately, all FADN sub-regions are smaller than NUTS-II regions and as such could be fitted[58]. Defining farm types, FADN relies on the EU-typology (Commission decision 85/377/EEC) that discriminates between 8 main farm types[59]. The dividing criterion is the economic contribution of single production branches to the entire farm income. A uniformly common basis is created by building this criterion on the Standard Gross Margin (SGM), a regionally uniform predefined gross margin per product. The concept of SGM seems straightforward, so that for EU-EFEM the FADN classification of farm types has been maintained.

The FADN claims that the farms constituting its dataset are allegedly representative of the universe of European farms larger than one hectare of agricultural land. Logically, for the FADN dataset, the entire universe of farms cannot be surveyed. Only from a field of observation certain farms are surveyed. The field of observation is restricted to commercial farms[60], which are defined according to national thresholds (see Annex 2). The representation of the universe is enlarged by a weighting factor applied to a cell[61] defined by the three dimensions of stratification (regional affiliation, size class, and farm type). The stratification of cells is not uniform, but accounts for potentially empty cells (e.g. arable farmland not represented in Ireland) (see FADN Clustering Schemes in Annex 4). The weighting factor is per stratified cell and gives expression to the ratio between the number of holdings in the universe and in the sample.

For EU-EFEM, the FADN farms are weighted by the FADN weighting factors before being averaged over the single NUTS-II regions. The outcome is the EU-EFEM average farms. The purpose of weighting with the FADN weighting factor is to balance over- or under-representations in the field of observations.

---

[58] In the Portuguese ‘PT11’ and ‘PT16’ the FADN sub-regions had to be split in order to fit NUTS-II regions. The region “fragments” were weighted according to the farms represented per region. The intersection of FADN and NUTS had to be done manually, since the single common reference, the regions’ names, partially differed in their writing.

[59] These types are defined: (1) Specialist field crops, (2) specialist horticulture, (3) specialist permanent crops, (4) specialist grazing livestock, (5) specialist granivore, (6) mixed cropping, (7) mixed livestock, and (8) mixed crops-livestock.

[60] “(…) Farms large enough to provide a main activity for the farmer and a level of income sufficient to support his or her family.” (FADN, 2006, Defining the field of observation)

[61] The FADN dataset considers 66,744 cells composing of 103 FADN regions times 9 size classes times 72 farm types.

3.7.2 Regional and Farm Level Constraints

The idea behind the formerly described system of FADN weighting factors is to obtain regional representation through the sampled FADN farms. This means that the intention is to depict regional capacities by farm capacities multiplied by a correspondent weighting factor. However, this system is conceived to represent the economic power of the farms of a region. At the same time, the representation of other agricultural capacity resources is limited. This circumstance and the access of EU-EFEM to regional statistics[62] with data from 1990 - 2003, favoured the use of the regional statistics against the FADN system.

For EU-EFEM, the most important capacities considered are UAA, livestock numbers, and production rights. They are all integrated as maximum constraints into the model. The UAA is integrated in its components grassland and arable land[63], while vegetable or special crop areas are exempted. For livestock numbers, it would also be preferable to integrate single livestock categories (e.g. demographic classes) since the difference in economic and ecological implications can be large. However, the regional statistics used do not show the desired degree of detail. For EU-EFEM, this gap was bridged by copying the livestock demography and the relations between the animal age classes, found in the FADN accountancy data and also in the regional data. So, regional capacities of livestock numbers per age class and category could be considered. For their outstanding economic importance to farms, sugar beet and potatoes were formulated a second time as single regional constraints, although they already formed part of the UAA. Since all regional constraints are entered as maximum constraints, this procedure limits the cultivation of sugar beet and potato, similarly to a quota regulation. For products that underlie production rights, the extent of the production rights was assumed to correspond to the historic extent of production found in the regional statistics used[64]. Milk quotas, in contrast to other quotas, are not taken from the regional statistics but from the FADN accountancy data. The loss of accuracy is extenuated by the advantage of depicting the cows' performance in statistical farm level data.

---

[62] NEWCRONOS, phase I, (EUROSTAT).

[63] No item for arable land is shown explicitly in the used database NEWCRONOS. A substitutive value was calculated by adding up the area of cereals, dry pulses, potatoes, sugar beets, oilseeds, fodder roots, brassicas, other fodder plants (incl. silage cereals), fallows, and set-aside.

[64] This assumption simplifies reality since production rights are not always used up.

3.7.3 Extrapolation Approach

The modelling units of the farm type model EU-EFEM are single farms. In comparison to a regional model, the computational effort is substantially increased, but aggregate errors decreased especially in cases of large intraregional heterogeneity. However, a wider regional coverage is also not excluded for EU-EFEM. It thereby follows a bottom-up approach, i.e. from lower to higher regional coverage, or in the concrete case from farms to NUTS-II regions. The link between both levels is created by extrapolation.

For the extrapolation of the EU-EFEM farm results to regional level an approach is chosen that balances computational effort and aggregate error. The latter is minimised by selecting the most representative farms out of the accessed farms in the FADN accountancy dataset. In this study, this is understood to be guaranteed by falling back upon the average farms (section 3.7.1).

Technically farms are extrapolated to regions within a linear programming module based on the sector-consistent approach by KAZENWADEL (1999). The variables of the module are of the type “positive variables”, i.e. no negative activity level is allowed. The problem to be solved can be formulated as the minimisation of the objective function (*B*) under certain constraints (Formula 15):

Formula 14: Objective Function (B) of Linear Extrapolation Approach

$$B = \sum_{k=1}^{m} (c_k \times nDEV_k) + \sum_{k=1}^{m} (d_k \times pDEV_k)$$

with the indexes:

k	capacity
f	farm

with the variables:

$nDEV_{(k)}$	negative deviation of capacity k
$pDEV_{(k)}$	positive deviation of capacity k

and the coefficients:

$c_{(k)}, d_{(k)}$	objective values of capacity k (weighting factor)
$reg_{(k)}$	regional production capacity k

Formula 15: Constrained Regional Capacity (reg_k) in Linear Extrapolation

$$reg_k = \left| \sum_{f=1}^{n} (a_{kf} \times EF_f) \right| + nDEV_k - pDEV_k$$

with the variables:

$EF_{(f)}$	extrapolation factor of farm f

and the coefficients:

$a_{(k,f)}$	production capacity k of farm f

Kazenwadel inserted the weighting factors c(k) and d(k) to the objective function (*B*) for the purpose of balancing regionally over-/underrepresented capacities with respect to their economic importance. He expressed economic importance of regional capacities reg_k by assigning them their Standard Gross Margin (SGM). With a similar motivation, instead of minimising the positive and negative deviations, the quadratic positive and negative deviations could also be minimised. This would lead to a more equal distribution of deviations over all capacities, since high deviations were penalised over-proportionally.

With the concept of the weighting factors c(k) and d(k), the main emphasis of the objective function can be shifted. Against the background of an economic-ecological model like EU-EFEM, the application of a pure economic weighting factor like the SGM that eclipses ecological aspects appears questionable. An example is the simulation of soil borne emissions. These depend mainly on the degree of representation of cash crops, but also on that one of total grassland and of arable land. A second problem[65] lies in the determination of the SGM itself. Production factors that do not directly render a marketable good (e.g. grassland) require that a substitute value is estimated. This relatively uncertain estimate militates for an alternative weighting system.

Apart from its potential to represent (empiric) economic performance of farms, the extrapolation approach should represent (empiric) farm structure, as well. Farm structure, within the official Farm Structural Survey (FSS) for example, is understood as the number of farms per farm type. The integration of this farm structure into any linear extrapolation module faces hurdles. First, the direct integration via absolute

---

[65] The general rules for the calculation of SGMs according to EU accords are described in Annex 1 to the Commission Regulation 85/377/EWG dating to June-7-1985.

numbers of farms per farm type would mean fixing to the activity level of the farm type specific extrapolation factors (EF(f)), i.e. the value of the extrapolation factor would be predefined. Second, the share of farm types in the FSS could be fixed as a constraint for the farm types of the extrapolation approach. This is technically impossible, since the total number of farms in the solution (sum of EF(f)) is unknown ex-ante and thus no shares can be determined.

The alternative approach used for EU-EFEM keeps the original system of weighting factors based on SGMs used by Kazenwadel and simultaneously considers the representation of farm structure. It modifies the SGMs in order to account for uncertainties in the determination of the same, and it seeks to optimise the representation of the farm structure. First, the bias from the SGM is reduced by drawing back on regional SGMs (EUROSTAT, 2003) instead of local SGMs, and second by conducting a sensitivity analysis for SGMs varied by 50%. The sensitivity analysis demands a technical solution in order to simulate the stepwise variations of the original SGMs. Out of the simulations, the ones that show an impact on the extrapolation factor (EF(f)) are preselected (first three reactions to 50% increase and to 50% decrease of SGMs). Also the reference simulation with the original SGM was preselected. Out of this pre-selection, that solution is chosen which best represents the shares of farm types given by the FSS and simultaneously shows minimal capacity deviations (nDEV(k) and pDEV(k)). In summary, the approach used for EU-EFEM, modified and expanded the original approach by Kazenwadel and by introducing trial methods, picks out from a selection of possible solutions the most appropriate one with respect to the representation of farm structure.

A deficiency of linear extrapolation approaches[66] becomes manifest in case farms which are a linear combination of one other farm are extrapolated. This problem was partially by-passed by constraining the maximum activity level of the extrapolation factors. However, this is a strong intervention which should be avoided as far as possible.

---

[66] DE CARA and JAYET (2000) applied an alternative approach for the calibration of FADN farms forming the basis to their LP-model. They combine Monte-Carlo methods and gradient algorithms constraining the maximal variations of calibrated parameters. In so doing, the adaptation is not in the farms, but in the activities' coefficients. Their proceeding assumes FADN farms weighted by FADN weighting factors to perfectly represent regional production.

3.7.4 (Calibrated) Typical Farms in the Model

In the former sections, the deduction of the average farms from the real farms contained in the FADN accountancy data was explained. In this study, “*typical farms*” and “*calibrated typical farms*” are distinguished from these average farms. Only in this section, typical farms will be discriminated against calibrated typical farms. The calibrated typical farms are the modelling units of EU-EFEM. But in order to maintain brevity, outside this section, typical farms will be referred to, although this actually means calibrated typical farms.

The first evolve from the latter by slight modifications with respect to marginal capacities of reduced expressiveness. The typical farms are further discriminated against typical calibrated farms that already reflect the adjustments for deviations of farm capacities from regional capacities. The calibrated typical farm finally represents the farm to be modelled in EU-EFEM.

The typical farms evolve from the average farms. Because of reasons (mentioned in section 3.7.1) of representation and expressiveness marginal capacities are ignored and sometimes fractions are rounded to integer numbers. From the typical farms evolve the calibrated typical farms. The extrapolation approach is applied to the typical farms. The extrapolation approach presented in the previous section leaves room for capacity deviations between regional and extrapolated farm capacities. Since the regional capacities are fixed, the capacity deviations have to be copied to the farm capacities. This is done via a calibration term that transforms the original farm capacities a(k,f) of the typical farms to the modified capacities a’’(k,f) of the calibrated typical farms. The calibration term is presented in Formula 16.

Formula 16: Adaptation of Farm Capacities to Regional Deviations

$$a''_{kf} = a_{kf} \Big/ 1 - \left(\frac{nDEV_k - pDEV_k}{SGM_k - reg_k} \right)$$

The transformation from the average farm, to the region typical farm, to the calibrated region typical farm is illustrated for an example in Table 57. The first modification is to the marginal capacities and real values of average farms. It is done manually because whether a farm capacity is marginal or not depends on the regional capacity[67]. The definition of "marginal" is dependent on the region and thus would have required considerable automation effort. The second modification is to the capacities of typical farms. The modification is uniform according to the presented calibration term and thus could be automated easily.

Table 57: From Average to Calibrated Typical Farms of EU-EFEM (Example)

		Before Extrapolation		**After Extrapolation**
Item	**Unit**	**'Average'**	**'Typical'**	**'Calibrated Typical'**
Capacities				
arable land	(ha)	42.5	42.5	43.6
grassland	(ha)	5.0	5.0	0.0
cattle	(LU)	12.5	12.5	0.0
pigs	(LU)	6.9	0.0	0.0
sheep	(LU)	0.3	0.0	0.0
potato	(ha)	5.6	5.6	1.1
sugar beet	(ha)	10.1	10.1	3.1
Non Calibrated Items				
diesel	(l)	5,595.3	5,595.3	5,885.8
milk per cow	(kg)	4,222.0	4,222.0	4,222.0
cattle premiums	(€)	2,052.6	2,052.6	0.0
diesel_dev	(%)	130.0	130.0	130.0

The preceding process is valid for the considered capacities. However, apart from the considered capacities, the farms simulated in EU-EFEM are also characterised by some additional items. These include diesel consumption per farm, milk yield per cow, total cattle premiums, and diesel deviation factor, representing the deviation between the theoretical diesel consumption according to the KTBL engineering data and the consumption stated in the FADN accountancy data. All these items are summarised in Table 57 under the term "Non-Calibrated Items".

Among the Non-Calibrated items, 'diesel' takes an outstanding position since it should follow the capacity adaptations performed on the way from the average to the calibrated typical farm. The milk yield per cow and the cattle premiums (national ceilings would be affected if it was changed on a farm level), in contrast, should not follow the capacity deviations. Correspondingly, the diesel consumption stated for the average farms is modified proportionally to the capacities' deviation. The modification is specific to the capacity like can be seen in Table 58. For arable land 100 l of diesel

---

[67] Even though this procedure is executed manually it is not arbitrary, but subject to certain rules. Grassland is modified proportionately to ruminant animals that are normally fed from grassland so as to maintain the original stocking density. Other plant production capacities are not modified since the interpretation is far less complex because of missing interrelation to other production branches.

are added or subtracted per unit. This quantity approximately corresponds to the average consumption for normal crop mix under central European conditions. Potatoes are implicitly contained in the assumed crop mix of arable land, so that the capacity adjustment of the potato area only accounts for the difference between “usual” arable crops and potatoes (additional 25 l/ha). Grassland and livestock values are very rough estimates.

Table 58: Standard Modification of Diesel Consumption per Farm Capacity

Capacity	**Diesel** (l/ha)	**Capacity**	**Diesel** (l/LU)
arable land	100.0	cattle	100.0
grassland	25.0	pigs	20.0
sugar beets	0.0	poultry	20.0
potatoes	25.0	sheep or goats	5.0

4 Modelling Results

In this chapter the results from several modelling exercises are presented. The exercises address economic and ecological research questions for a number of scenarios dealing ultimately either with soil carbon accumulation or biogas production.

The model is firstly validated in order to allow evaluating the expressiveness of generated scenario results and also the model's quality. Second, a common reference, to which the scenarios can be compared, is created. This reference is free of any scenario obligations, but simulates the actual situation of agricultural production. Third and finally, scenario results are calculated and presented. Each scenario is subject to specific scenario rights and obligations that are essentially in addition to the restrictions of the reference scenario.

In terms of presentation of results, there is typically a trade-off between results' aggregation and information content. Thus only an optimal balance between both can be sought. Data aggregation is indispensable for this study since EU-EFEM generates more than 600 values per analysed parameter (up to 4 farms for 163 NUTS-II regions[68]). This aggregation is mostly done to a regional level. Since also the regional level still means 163 values per analysed parameter, the presentation is in the form of GIS maps. This allows for a rapid access to the results and the identification of "hot-spots" in the EU-15. In the GIS maps however the presentation is not of numeric values and thus grouping into optically different structures is necessary. Further, on level of selected regions, also farm level results will be shown to highlight the importance of farm types to the results.

4.1 Model Validation

Model validation helps to reveal model strengths and weaknesses (McCarl and Spreen, 2004). Fundamentally, validation criteria and objects are subjective and determined by the tester. In the current application, the selected criteria are chosen in a way to assure consistency with economic theory and real world contexts as

---

[68] Since EU-EFEM utilised a newer NUTS-II definition (2005) and some regions were left out because of missing data, a total of 134 regions is simulated.

perceived by the modeller. The simulation of real world contexts can be validated against the model's reference situation (section 4.2). In contrast to the reference situation, the done scenario runs simulate future or unknown situations where empirical data for cross-check is not available. So, scenario results can only be validated against consistency with economic theory.

In terms of the letter, it can be stated that in the development of EU-EFEM, conformity with economic theory, agricultural and environmental correlations, and interactions between these modules has always been a decisive design criterion. The model's reactions will conform to economic theory and reflect main agricultural correlations, although they conform to the latter often through simplifications like feeding modules. The basic structure of EU-EFEM is a Mixed Integer Programming (MIP) model. This type of model, if applied adequately, is suited for the depiction of micro-economic contexts.

In the validation of the model's reference situation against the real world context, the following should be considered. EU-EFEM follows a bottom-up approach, starting from farms as smallest modelling unit and ending up at NUTS-II-level. Maximal consistency between farm and regional level is guaranteed by the chosen extrapolation approach (section 3.7.3). It thus suffices to validate either regional or farm level results since the other will automatically be in line.

However, from the beginning, a 100% accurate simulation of real world contexts has not been expected as the model draws back on a mixture of data rows and data points. The empiric data that the simulations are compared to does not represent an equal mixture. Although the reference year is 2003 and the political conditions of 2003 are laid down to the reference situation, production data represents an average of the data row 2001 – 2003.

The validation of the reference situation is done first for the main production factors UAA, arable land, grassland, and animal numbers. The utilisation of UAA, arable land and grassland is simulated at 100% accuracy by EU-EFEM. In the model deviations to the empirical data are simply not allowed because all land has to be cultivated. Only in case a farm completely abandons production, then land utilisation falls short. Changing arable land to grassland is not an option.

In Table 59 the simulation of animal production is validated through the model's parameter "unused capacities". It reflects the number of Livestock Units (LU) compared to the empiric data. For the reference year the model simulates 5,602,725 LU less than the statistical value corresponding to 5.9% of the statistical total (average from 1990 to 2003 according to EUROSTAT's NEWCRONOS). This deviation is small and still acceptable.

Table 59: Unused Animal Capacities in Reference Situation

Country	LU	Country	LU	Country	LU
Austria	165,193	Germany	909,298	Netherlands	140,704
Belgium	335,133	Greece	6,554	Portugal	22,792
Denmark	94,404	Ireland	859,286	Spain	89,784
Finland	55,187	Italy	518,864	Sweden	159,394
France	2,227,422	Luxembourg	18,710	**Total**	**5,602,725**

It would be most desirable to not only compare animal numbers but also animal sub-categories. However, EU-EFEM's animal categories are defined according to marketable products. In the applied empiric EUROSTAT data no similar categories are shown, but only average slaughter weights. Thus a more detailed validation of the simulation of animal production is not possible.

In terms of plant production validating merely the representation of UAA, arable land and grassland probably does not pay sufficient tribute to the complexity of agricultural production. So, in the following the simulation of crop rotations will be analysed, a major determinant of ecological and economic impacts of plant production.

Empiric data on crop rotations is taken from EUROSTAT's NEWCRONOS data base. Unfortunately, NEWCRONOS is not in complete conformity to EU-EFEM with respect to contained crops (partially due to the limited number of crops in EU-EFEM). In order to create congruency between NEWCRONOS and EU-EFEM results, the rough categorisation into cereals, maize, tuber crops, and other non-cereals was applied.

On the level of the EU-15, EU-EFEM simulates crop rotations rather well (see Table 60). The largest deviation is in maize, where EU-EFEM shows a by 7.3%-points reduced share in the crop rotation, equal to a representation of only 64.3% of the statistic share. In tuber crops EU-EFEM's under-representation is by 0.4%-points, equal to 92.5% of the total production. Cereals and "others", in turn, are overrepresented. EU-EFEM represents 113.6% of the statistical cereal production and 102.0% of the production of other non-cereals ("ONC").

Table 60: Crop Shares in EUROSTAT Statistics and in EU-EFEM

	Cereals	Maize	Tubers	ONC
			(%)	
Statistics (1990 - 2003)*	52.1	18.0	5.3	24.7
EU-EFEM (2003)	59.2	10.7	4.9	25.2
EU-EFEM : Statistics	**113.6**	**64.3**	**92.5**	**102.0**

**This was the period agreed within the INSEA-project and for which data was available to this study.*

On a regional level the representation quality is not uniform (see Table 61). For this judgement the NUTS-I regional level is chosen. In the NUTS-I-regions BE3 (Wallonne), EL2 (Kentriki Ellada), and FR2 (Bassin Parisien) the representation of the crop rotation is rather good. In contrast, in Austria, for example, maize is heavily underrepresented. According to the statistics, in Austria the share of maize in the crop rotation varies between 20% and 50%. The model, however, simulates shares between 1% and 6% only. Generally, maize production is rather underestimated by the model. Overrepresentation is only found in some South European regions (in 5 Italian, 4 Spanish, and 2 Greek regions). The share of tuber crops is met nearly exactly in all simulated regions which can be attributed to the extraordinarily high competitiveness of tuber crops in comparison to other cultures and thus their economic importance to the farm gross margin.

Table 61: Crop Shares* in EUROSTAT Statistics and EU-EFEM References on NUTS-I-Level

	Reference Run (2003)				Statistics ('99 - '03)					Reference Run (2003)				Statistics ('99 – '03)			
Nuts	**CER**	**MAZ**	**ONC**	**TUB**	**CER**	**MAZ**	**ONC**	**TUB**	**Nuts**	**CER**	**MAZ**	**ONC**	**TUB**	**CER**	**MAZ**	**ONC**	**TUB**
	(fraction)									(fraction)							
at1	0.65	0.04	0.24	0.07	0.57	0.19	0.17	0.07	**es4**	0.66	0.13	0.18	0.03	0.75	0.08	0.13	0.03
at2	0.73	0.01	0.26	0.01	0.21	0.51	0.27	0.01	**es5**	0.48	0.26	0.26	0.00	0.64	0.26	0.09	0.01
at3	0.60	0.06	0.31	0.03	0.44	0.36	0.16	0.03	**es6**	0.57	0.15	0.25	0.04	0.61	0.05	0.30	0.05
be2	0.49	0.19	0.14	0.18	0.23	0.42	0.15	0.19	**fi1**	0.83	0.00	0.14	0.03	0.60	0.00	0.37	0.03
be3	0.50	0.14	0.15	0.21	0.49	0.16	0.13	0.22	**fr2**	0.52	0.12	0.30	0.07	0.54	0.14	0.26	0.07
de1	0.50	0.11	0.35	0.04	0.64	0.16	0.16	0.04	**fr4**	0.49	0.17	0.33	0.01	0.47	0.27	0.25	0.01
de2	0.42	0.14	0.38	0.07	0.57	0.20	0.16	0.07	**fr5**	0.51	0.15	0.34	0.00	0.31	0.30	0.39	0.01
de4	0.74	0.00	0.23	0.03	0.58	0.13	0.25	0.03	**fr6**	0.52	0.14	0.34	0.00	0.27	0.35	0.37	0.00
de7	0.56	0.03	0.35	0.06	0.69	0.08	0.17	0.06	**fr7**	0.47	0.16	0.36	0.01	0.35	0.27	0.36	0.01
de8	0.73	0.00	0.21	0.06	0.60	0.09	0.26	0.06	**fr8**	0.58	0.06	0.35	0.01	0.55	0.18	0.26	0.01
de9	0.48	0.01	0.35	0.16	0.56	0.19	0.09	0.16	**ie0**	0.60	0.00	0.31	0.09	0.31	0.03	0.59	0.06
dea	0.60	0.02	0.27	0.11	0.58	0.23	0.08	0.11	**it1**	0.64	0.16	0.18	0.02	0.45	0.37	0.17	0.02
deb	0.54	0.04	0.34	0.09	0.71	0.05	0.14	0.09	**it2**	0.56	0.28	0.12	0.04	0.27	0.49	0.20	0.04
dec	0.56	0.10	0.33	0.01	0.75	0.09	0.16	0.01	**it3**	0.56	0.20	0.18	0.07	0.14	0.52	0.26	0.07
ded	0.60	0.01	0.35	0.04	0.58	0.10	0.27	0.04	**it4**	0.53	0.19	0.18	0.10	0.34	0.12	0.43	0.11
dee	0.70	0.00	0.20	0.10	0.62	0.09	0.19	0.10	**it5**	0.64	0.13	0.18	0.05	0.50	0.11	0.33	0.05
def	0.64	0.00	0.32	0.04	0.57	0.13	0.26	0.04	**it6**	0.52	0.28	0.18	0.02	0.40	0.34	0.23	0.02
deg	0.61	0.00	0.34	0.04	0.65	0.09	0.23	0.04	**it7**	0.63	0.15	0.18	0.04	0.57	0.06	0.32	0.05
dk0	0.85	0.00	0.11	0.04	0.69	0.10	0.17	0.04	**it8**	0.50	0.31	0.16	0.03	0.53	0.22	0.20	0.04
el1	0.62	0.27	0.10	0.01	0.75	0.14	0.07	0.04	**it9**	0.67	0.10	0.20	0.03	0.81	0.09	0.07	0.03
el2	0.57	0.27	0.14	0.02	0.57	0.25	0.14	0.04	**lu0**	0.71	0.09	0.19	0.01	0.50	0.21	0.27	0.01
el4	0.53	0.26	0.17	0.04	0.56	0.31	0.08	0.06	**nl0**	0.48	0.06	0.21	0.26	0.22	0.29	0.23	0.26
es1	0.35	0.49	0.15	0.11	0.17	0.41	0.39	0.14	**pt1**	0.78	0.15	0.05	0.02	0.40	0.46	0.08	0.06
es2	0.53	0.17	0.30	0.00	0.76	0.13	0.09	0.01	**se0**	0.77	0.00	0.19	0.04	0.49	0.01	0.46	0.04

** Crop shares of crop groups (CER: cereals, MAZ: maize, ONC: other non-cereals, TUB: tuber crops).*

4.2 Reference Situation

The reference situation is for the year 2003[69]. The model's reference situation reflects the optimised situation with maximal total farm gross margin under a set of given production restrictions. The farm shows an optimal combination of production options which are produced at optimal intensity and at minimal costs. The yield values laid down to the simulated reference situation are the regional EPIC values which stand in contrast to EU-EFEM's alternative of nationally averaged EPIC yield values (compare section 3.3.3). Regional EPIC yield values are also utilised in Scenarios 1 and 2.

4.2.1 Economic Reference

The economic reference situation builds on the optimisation of EU-EFEM's objective function, which is the maximization on the total gross margin under certain constraints. Similar to the study regions' diversity in production conditions, it is awaited that the total gross margin will show a diverse regional picture. For reasons of comparability of gross margins from various farms, gross margins are given as per hectare of UAA.

The total gross margin per hectare of UAA is from 50 € in Vorarlberg (Austria) to 5,361 € in Brabant-Wallon (Belgium). Vorarlberg is a region dominated by dairy production and although at relatively high intensity (stocking density of 1.84 LU/ha) local milk yields are low (5,000 - 5,700 kg/cow/year). In Brabant-Wallon a large area share is arable land and cultivated with profitable cash crops like sugar beet or potatoes and this falls together with local high yields.

For the EU-15 the total gross margin (GM) per hectare of UAA is displayed grouped into five classes in Figure 12. Each class is of equal size, i.e. it consists of the same number of regions. Narrow class borders thus hint to a concentration of regions around the corresponding GM. The narrowest class is the second from above with gross margins from 689 to 967 €/ha.

---

[69] Remember that elements farther past are implied since apart from data points also data rows (e.g. average yields over several years) are referred to.

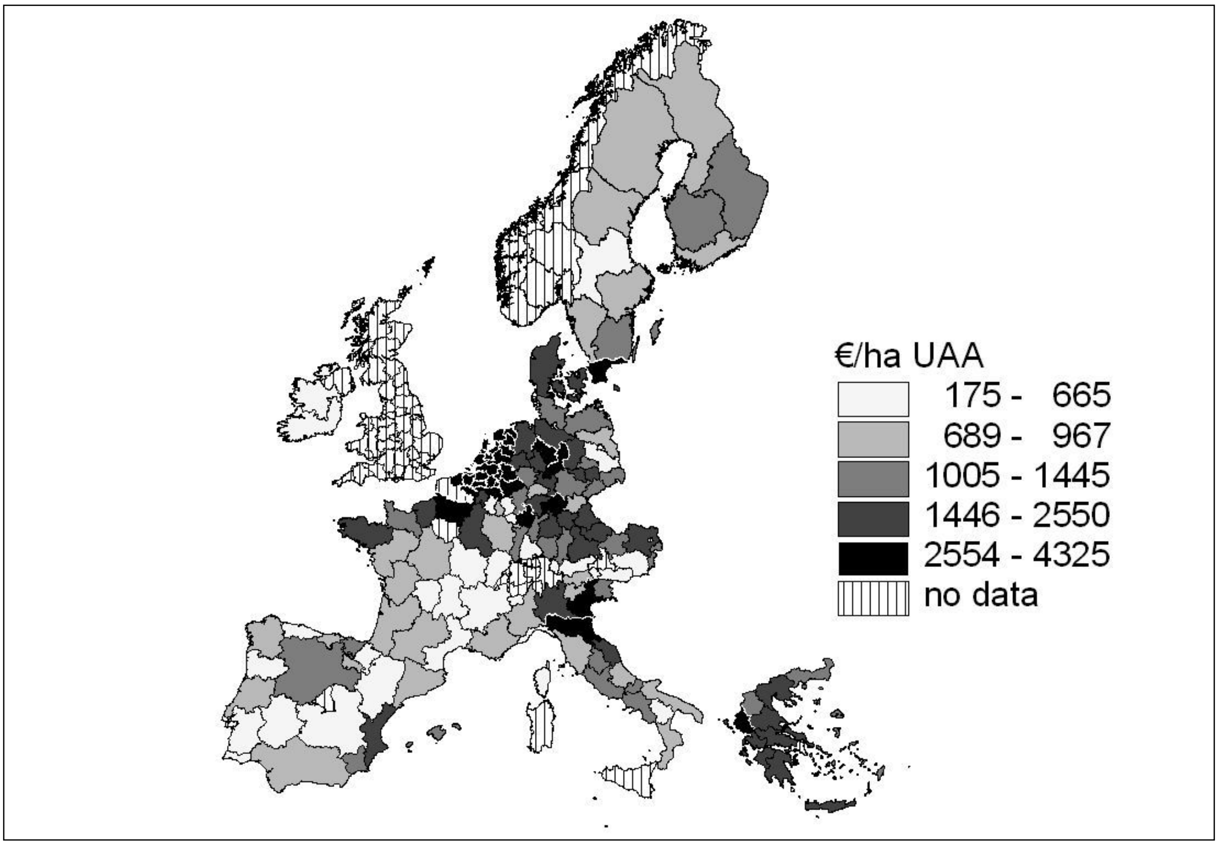


Figure 12: Regional Gross Margin in Reference

The presented comparison of GM per hectare of UAA is not beyond doubt. It suggests a wide range of gross margins from the beginning, since the UAA consists of arable land and grassland, typically two land-use forms of different area profitability. So this parameter will not be analysed in further detail. Breaking the GM further down, for single products, is, however, out of the scope of this study.

4.2.2 Ecological Reference

Describing the ecological situation in the reference is not as straightforward as for the economic reference situation, since a unique ecological parameter like in economics with the gross margin does not exist. Alternatively, the ecological reference situation is thus described at various parameters: GHG emissions, ammonia emissions, and SOC-dynamics.

The average GHG emissions, for comparability reasons on a per hectare basis, are illustrated in Figure 13. Thereby the emissions originally simulated on farm level are extrapolated to regions. The GHG emissions are in CO_2-equivalents[70] and are

---

[70] Based on GWP_{100} (definition of GWP_{100} in section 2.1).

grouped into five classes. The classes are of equal class width, each one representing a range of 3 tCO_2e. The emissions are of the sources manure management, enteric fermentation, fertiliser production, direct and indirect soil, purchased feed stuffs, and diesel consumption. As additional source respective sink the soil carbon pool of arable land[71] is considered. The GHG accounting approach is according to the option “others” in Table 26, which means, a combination of approaches which are alternative to IPCC-Tier 1 and Tier 2. Only emissions from the source “indirect soil” are accounted for with the IPCC-Tier 1 approach.

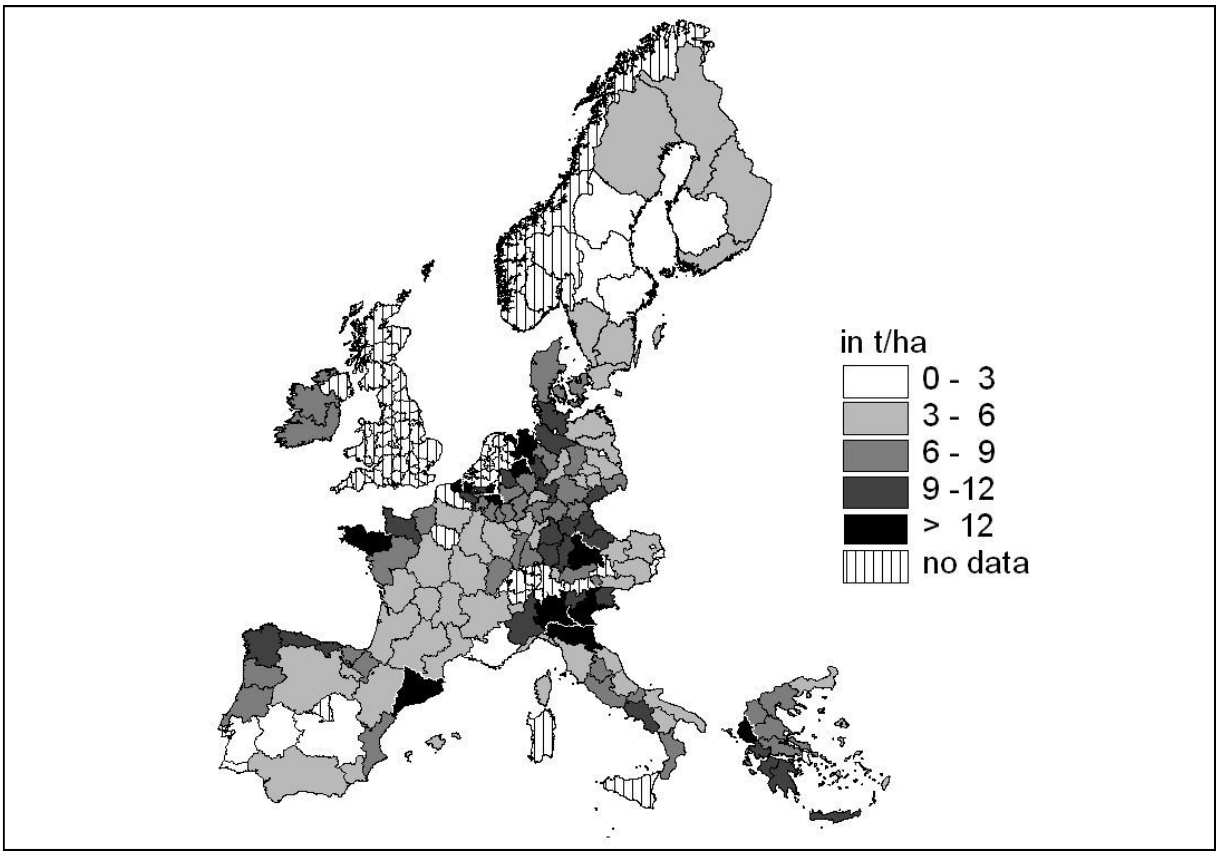


Figure 13: Regional GHG-Emissions in the Reference (per UAA)

In the presented emission map, the borders of the classes cover a range from zero to over 12 tCO_2e per hectare of UAA. The values delivered by the simulation are between 1.9 tCO_2e (Östran Mellansverige, Sweden) and 25.6 tCO_2e (Antwerp, Belgium). This means that in the latter region the emissions are over 16 times higher than in the first. Despite this wide range, emissions are nested in certain geographical zones like the Netherlands, Belgium, and the Italian Po valley. Zones of low emissions are Sweden, West Finland, Portugal and Spain except of Catalonia.

---

[71] Grassland, due to the lack of management alternatives in EU-EFEM that would change SOC-levels, is not analysed.

Not astonishingly, the emission map resembles very much a map of the stocking density (Figure 14). This confirms animal keeping as a major emission source. Especially in the Belgium and Dutch regions, the high animal density apparently entails considerable GHG emissions. However, both maps are only similar, but not equal to each other. In the Spanish Catalonia, for example, the highest national emission rates are found, although stocking densities are higher in other regions of the country. To a large extent this fact might be attributable the stocking density also including non-ruminant animals: for non-ruminants the link between animal numbers and GHG emissions is much looser.

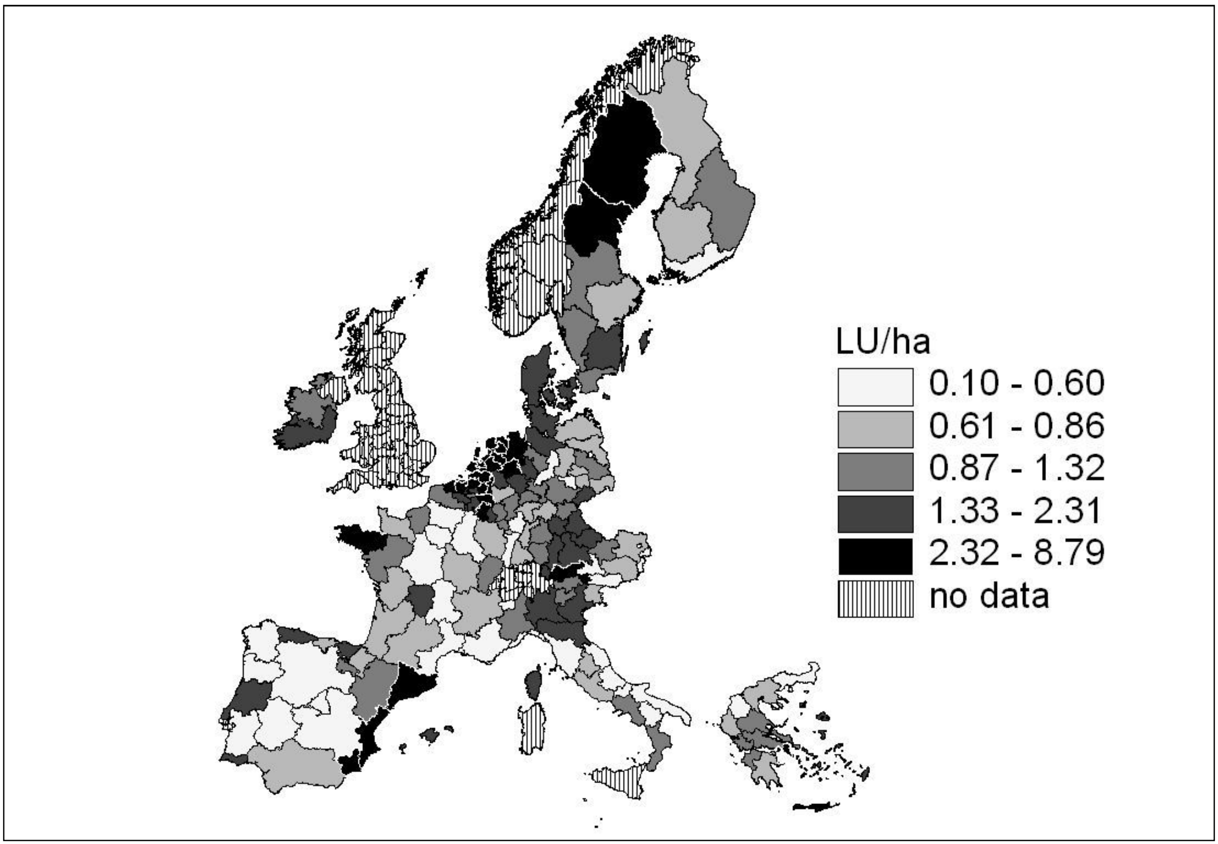


Figure 14: Regional Stocking Density in the Reference (per agrarian area)

Going more into detail and comparing the GHG-emission sources, on average, enteric fermentation presents as the largest emission source for the EU-15. It is responsible for over 32.4% of total emissions (for the emission sources represented above). Over 23.9% of emissions are from manure management, over 14.5% are indirect and around 11.2% are direct soil emissions. The production of synthetic fertiliser leads to around 8.9% of emissions, the consumption of diesel around 5.1%, and the production of purchased feed stuffs around 4.0%.

For the same seven GHG sources as above (enteric fermentation, manure management, production of synthetic fertiliser, direct soil, indirect soil, production of concentrated feed stuffs, and consumption of diesel and other purchased fodder), emissions are compared on a more detailed level in the following. In Table 62 GHG emissions per hectare of UAA are shown on NUTS-I-level. The largest interregional variation is found in the sources “enteric fermentation” and “manure management”. For these two sources, the highest emissions are in Belgium regions and in one East German region (‘DE2’, Lower Saxony). With respect to fertiliser production, the highest emissions per ha of UAA are found for Sweden (‘SE0’) and for one Greek region (‘EL2’, Kentriki Ellada). In the latter also direct and indirect soil emissions are highest: in particular, indirect soil emissions are significantly above the average level. Only one Italian region competes (‘IT3’, Nord Est). Emissions attributable to the production of concentrated feed stuffs are highest in one Belgium region (‘BE2’, Vlaams Gewest). Low emission levels from the sources “direct soil” and “indirect soil” are found in the Austrian regions. Emissions from “concentrated feed stuffs” and the “consumption of diesel” are relatively low everywhere.

Table 62: GHG Emissions acc. to Source in the Reference, NUTS-I-Level

		Emission Source*								Emission Source*					
NUTS	**ENT**	**STOR**	**FER**	**DIR**	**IND**	**FOD**	**PUR**	**NUTS**	**ENT**	**STOR**	**FER**	**DIR**	**IND**	**FOD**	**PUR**
			(tons of CO_2e/ha of UAA)								(tons of CO_2e/ha of UAA)				
at1	2.2	0.4	1.5	0.3	0.1	0.3	0.7	**def**	4.4	3.1	0.7	0.9	0.6	0.2	0.3
at2	4.2	0.7	1.2	0.3	0.1	0.4	0.4	**deg**	2.1	1.9	0.6	0.6	0.4	0.1	0.4
at3	9.8	1.1	1.4	0.4	0.1	0.8	0.8	**el1**	3.4	3.9	3.3	4.5	9.3	0.1	2.2
be2	36.7	28.1	4.2	5.6	3.7	5.6	2.6	**el2**	4.8	12.5	4.8	6.0	13.4	1.2	3.0
be3	21.7	10.8	3.4	4.4	2.3	0.9	1.9	**el4**	2.2	4.3	2.2	2.9	5.5	0.1	0.4
dk0	1.4	2.3	1.0	1.0	0.6	0.3	0.3	**ie0**	7.0	2.3	0.6	0.9	0.2	0.3	0.6
fi1	3.9	1.4	3.5	0.7	0.1	0.5	0.6	**it1**	4.2	2.7	0.8	1.8	4.7	1.0	0.8
fr2	11.8	7.5	3.9	4.5	2.4	0.6	1.8	**it2**	5.0	3.0	0.5	1.4	5.4	1.1	0.7
fr4	7.2	4.6	1.5	1.9	1.0	0.3	1.0	**it3**	7.6	8.6	1.4	3.2	12.2	3.2	1.6
fr5	8.0	8.4	1.4	1.7	1.1	2.0	0.9	**it4**	2.6	2.4	0.6	1.3	4.6	0.8	0.6
fr6	3.9	2.6	1.2	1.4	0.7	0.4	0.8	**it5**	1.6	2.8	1.3	2.2	7.2	0.9	1.1
fr7	4.0	2.8	0.7	0.9	0.5	0.3	0.4	**it6**	1.7	0.7	0.5	0.8	2.5	0.3	0.3
fr8	1.5	1.0	2.3	2.0	1.1	0.3	0.7	**it7**	1.7	1.7	0.7	1.3	3.8	0.6	0.8
de1	12.5	10.4	1.9	2.7	1.6	0.6	1.7	**it8**	2.6	1.5	0.5	0.9	3.4	0.5	0.6
de2	29.2	20.7	3.9	5.5	3.4	1.4	3.3	**it9**	2.6	1.3	1.0	1.8	5.4	0.4	1.0
de4	3.7	2.6	1.2	1.1	0.6	0.1	0.6	**lu0**	3.6	0.9	0.7	0.8	0.5	0.1	0.5
de7	7.7	6.6	1.7	1.9	1.2	0.4	1.2	**nl0**	7.5	4.0	1.0	1.5	1.1	1.7	0.5
de8	1.5	1.3	0.6	0.6	0.4	0.1	0.3	**pt1**	4.7	2.2	1.3	2.8	5.1	0.6	1.1
de9	12.2	12.2	2.6	3.2	2.0	1.4	1.6	**es1**	9.0	4.1	1.7	3.5	7.2	1.0	0.9
dea	19.3	18.4	3.8	4.7	3.2	1.4	2.2	**es2**	3.1	2.6	2.4	3.5	6.1	0.3	0.9
deb	6.9	4.9	1.7	1.9	1.1	0.4	1.3	**es4**	0.9	1.4	1.0	1.7	2.3	0.1	0.4
dec	2.3	1.5	0.4	0.5	0.3	0.1	0.3	**es5**	4.3	6.1	1.6	2.9	6.2	0.9	1.2
ded	7.4	7.0	1.9	2.1	1.3	0.6	1.1	**es6**	1.0	1.1	0.7	1.2	1.9	0.1	0.4
dee	4.1	4.1	2.3	2.2	1.3	0.4	0.9	**se0**	6.6	1.1	4.8	1.1	0.2	0.8	2.5

**GHG-Emission Sources: ENT: enteric fermentation, STOR: Manure management and storage, FER: fertiliser production, DIR: N_2O-direct soil emissions, IND: N_2O-indirect soil emissions, FOD: production of concentrated feed stuffs, and PUR: equivalents for purchased fodder and diesel.*

Although they do not form part of the greenhouse gases under the Kyoto climate regime, ammonia emissions have an ecological dimension and were analysed in this study. Ammonia is an important environmental pollutant, especially with respect to eutrophication. Overall ammonia emissions sum up to 1,174,269 tons respective 967,045 tons of NH_3-N (ammonia nitrogen) for the EU-15. This quantity corresponds to 12.68 kg NH_3/ha respective 10.45 kg of NH_3-N/ha. The sources included in this analysis are “application of synthetic fertiliser” (38% of total), “production of synthetic fertiliser” (3% of total), the whole chain of “organic fertiliser management” (58% of total), and “purchased fodder” (1% of total). The latter is because in EU-EFEM the emissions related to purchased fodder, i.e. produced elsewhere, are assigned to the buying farm.

4.3 Scenario 1: Minimum Share of Conservational Tillage

The scenario 1 is based on the values of the reference situation, i.e. of the year 2003. The scenario “Minimum Share of Conservational Tillage” originates from the idea of stimulating soil carbon accumulation by promoting conservational tillage. In EU-EFEM, conservational tillage comprises mulch seeding and no-till. It is hypothesised that mulch seeding and no-till significantly contributes to carbon sequestration in the form of soil carbon accumulation. Therein, two processes are benefitted from: first, conservational tillage features less soil disturbance than conventional tillage, thereby slowing down the decay of soil organic matter and secondly, conservational tillage brings along constant mulch cover and increased organic matter input into the soil. It is further hypothesised that conservational tillage represents a cost efficient means for carbon sequestration because less field trips, less labour and fuel are necessary.

The scenario obligation mandates farmers to work a certain minimum share of their arable land under conservational tillage. From its logic the obligation is restricted to arable land, since grassland is not tilled by definition (in this study grassland is understood as permanent grassland). The single relevant measures to comply with the scenario obligations are the introduction of no-till and mulch seeding. The yields laid down in this scenario are the yields simulated by EPIC for conventional tillage, mulch seeding, and no-till. The scenario endows farmers with the freedom to decide upon the fields and crops to be dedicated to conservational tillage and to over-accomplish the mandatory minimum share of conservational tillage. However, farmers are restricted by EU-EFEM to not exceed 50% of the share of mulch seeding with no-till, i.e. the relation between no till and mulch seeding must not be above 1:2.

The scenario's objective is to assess the economic consequences of the forced minimum conservational tillage share. The assessment compares the change of gross margin due to the scenario obligations by comparing the gross margin in the scenario to the one in the reference situation, a situation in which conservational tillage is not allowed, as mentioned beforehand. In order to achieve comparability among different farms, results will uniformly be referred to farmed area (in hectares).

The scenario will analyse the following four cases whereby the first case is appended for comparison purposes as scenario specific baseline:

- min00 Minimum 0% conservational tillage for arable land, but conservational tillage is free of choice (baseline),
- min40 Minimum 40% conservational tillage for arable land,
- min70 Minimum 70% conservational tillage for arable land, and
- min100 Minimum 100% conservational tillage for arable land.

The above restrictions apply on a farm level. The results will be presented on a farm, regional, and European level. On a farm level all farms with a valid solution are presented. Since regional and EU-15 results evolve from extrapolated farm level results, only regions where all farms represented in the same region show a valid solution are included. On EU-15 "average level", in contrast to the earlier "mean level", only regions where all farms and all scenario cases show a valid solution are included. So, the average representations are of a more conservative value than the mean, since regions with any scenario case or any represented farms without valid solution are excluded from the calculation.

4.3.1 Regionalized Results

In scenario case 'min00', no scenario obligations effectuate since the forced minimum share of conservational tillage is 0%. The first scenario case with scenario obligation is 'min40', with a 40% minimum share of conservational tillage. Figure 15 shows the accomplishment and over-accomplishment expressed in percent points.

An over-accomplishment by 0%-points would mean that the 40%-limit is just fulfilled, while an over-accomplishment by 20%-points is equal to a total share of conservational tillage of 60%.

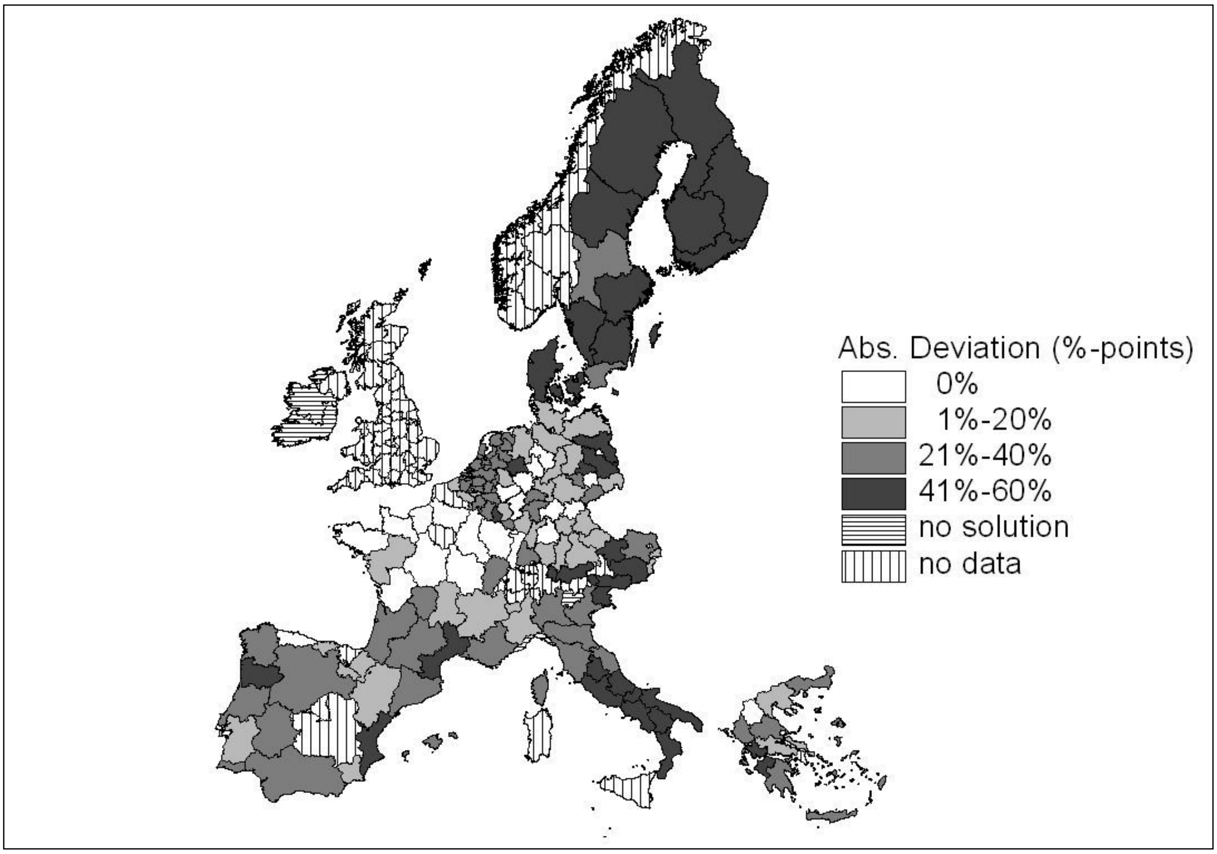


Figure 15: Conservational Tillage exceeding Forced 40% Share

From Figure 15 it can be seen that the overwhelming majority of regions complies with the 40% limit. Only two Irish regions return no valid solution under the set constraints. Above that conservational tillage is not expanded and no additional unit of arable land is rededicated to conservational tillage in few regions, i.e. the 40%-limit is not over-accomplished, as is the case in the North of France (Parisian plain) and in the North-West of Germany. On the opposite, many regions are in the class where the adoption rate of conservational tillage is largest ranging from 81% to 100% and corresponding to the class 41%- to 60%-points of over-accomplishment. These regions concentrate in Scandinavia, South Italy, Austria, and East Germany.

In the scenario case 'min70', a 70% minimum share of conservational tillage is enforced (see Figure 16). Still, the general picture resembles that of 'min40', although the intensity of impacts has notably increased. In 'min40', only a few regions in France and Germany did not over-accomplish the forced 40% limit. In 'min70' the number of these regions is significantly higher, but regionally still is concentrated in France and Germany. In both countries, farmers seemingly face strong production constraints from the scenario obligation.

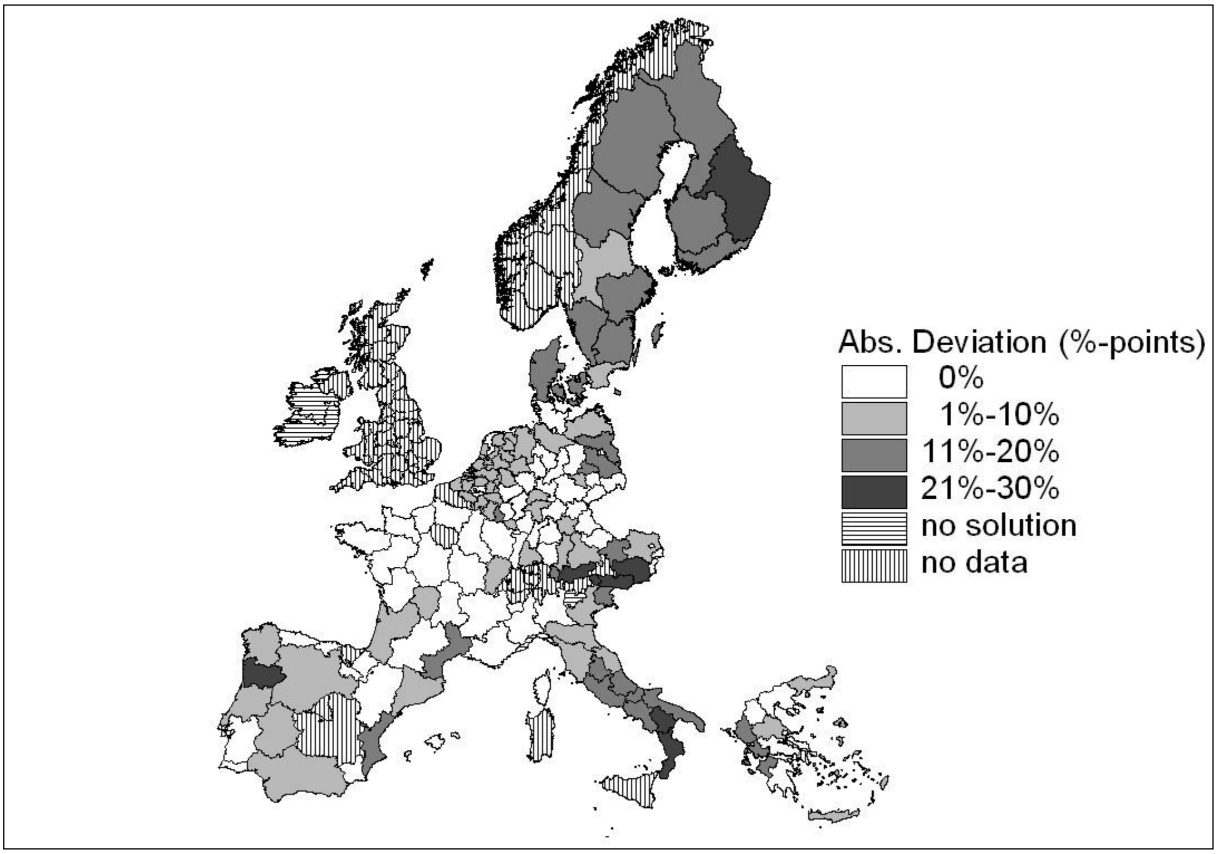


Figure 16: Conservational Tillage exceeding Forced 70% Share

For the cases ‘min40’ and ‘min70’, the grouping of results was into four classes. Logically, the class borders become narrower for ‘min70’, since the range of potential over-accomplishment is smaller. If we look at the highest rates of conservational tillage, which from ‘min40’ was assumed to be between 81%- and 100%, it can be established that there are few regions that obtain shares above 91%. These are the regions that show an over-accomplishment of above 21% under the case ‘min70’.

For the fourth scenario case ‘min100’, in which 100% of arable land has to be worked under conservational tillage, the question of over-accomplishment is unnecessary. But the question remains as to whether the regions comply, and if they do, which regions comply. The results will not be illustrated in another GIS-map, since they can be just as effectively summarised in a few words. Again the same two Irish regions return no solution, while all other regions achieve the mandated 100% share of conservational tillage.

In summary, it can be stated that the scenario obligations were fulfilled with very few exceptions in all scenario cases. The minimum share of conservational tillage is often over-accomplished. For such cases where over-accomplishment occurs, it can be assumed that introducing conservational tillage as a management option increases the farm gross margin. This and other economic effects will be analysed in the following section.

4.3.2 Selected Regions: Economic Results

This section is dedicated to the analysis of the scenario's economic impacts. In general, significant negative economic impacts are not expected since in all study regions farms complied easily with the scenario obligations and even over-accomplished (see previous section). It cannot be expected to gain much information from a general overview in GIS-maps, as was offered previously. It is thus appropriate to analyse and show results of selected study regions, but in greater detail.

In order to create an impression of the range of economic implications, the regions with the highest changes to the gross margin (negative and positive) are selected. In this way, the region with the highest average change over all scenario cases does not coincide with the region with the single most extreme value. Already this circumstance indicates the variety of adaptation options of farms. Finally, three regions are selected to represent the range of values: Liège (Belgium) is the region with the single highest negative change; Cologne (Germany), the region with the highest average negative change; and Itä Suomi (Finland), the region with the highest average positive change.

Table 63: Change of GM in Scenario 1, Extreme Regions (to Reference Situation)

			CVT Minimum Share			
Country	**Region**	**Unit**	**0%**	**40%**	**70%**	**100%**
Belgium	Liège	(€/ha)	9.03	9.03	5.67	-260.48
Germany	Cologne	(€/ha)	0.26	-2.77	-14.04	-148.93
Finland	Itä Suomi	(€/ha)	27.75	27.75	27.75	23.20

In the three selected most extreme regions for the scenario case of a minimum share of 0% CVT (conservational tillage) (scenario case 'min00'), the change in gross margin compared to the reference situation is always positive (see Table 63). This might not be too surprising, since conservational tillage is excluded for the reference situation, but is allowed free of choice in ‘min00’. (This means also that all other regions not displayed here do not have a negative change of GM in ‘min00’). In the Finnish Itä Suomi, the scenario cases entail a positive change of GM from approx. 28 €/ha (‘min00’), gradually going down to 23 €/ha along the scenario cases (‘min100’). The highest negative change is logically for ‘min100’, and occurs in Liège, where it is in excess of 260 €/ha. However, in Cologne the change of gross margin is negative in three of four scenario cases, while in Liège it is so only for one scenario case.

Some interesting insights can be gained looking at the selected extreme regions in more detail and looking for the reasons behind the variety of adaptation options in those regions. The negative changes of GM in Cologne can be traced to a rather high share of sugar beet in the crop rotation - their share is nearly a quarter - in combination with their high sale price and high regional yield. Sugar beet is one of the most profitable crops, but it is very humus demanding and highly sensitive to conservational tillage, according to EPIC simulations. The yield decrease can reach up to 17% in Cologne when no-till and conventional tillage are compared (if all straw is left to field decay). Because sugar beet features a comparatively high gross margin (due to high yield and high sale price), and because EPIC simulations indicated also a yield decrease for other crops in Cologne under conservational tillage, a substitutive reaction replacing sugar beet in the rotation is not attractive.

The picture in Liège is different, where the GM only decreases if conservational tillage is forced to 100%. There a notable substitutive reaction takes place: cultivation of maize is decreased by more than 66% from 12%-points to 4%-points, while the released area is cultivated with cereals. In Liège, other crops offer a rather cost efficient replacement of maize, and as a result, sugar beet is less in the crop rotation. Nevertheless, the simulated yield losses by EPIC even exceed the ones in Cologne: 29% for sugar beet under no-till (in case all straw is left to field decay). For the other crops, EPIC simulated yield decreases by 23% for wheat and barley under no-till (if all straw is left to field decay). Thus, forcing the 100% conservational tillage limit means also that sugar beet either has to be switched to conservational tillage or taken out of the crop rotation. This entails the single most extreme loss of GM found in the EU-15, with the 260.48 €/ha shown above.

In Itä Suomi (Finland), which features the highest positive change of GM, hardly any humus demanding crops are grown. In contrast to Liège and Cologne, neither sugar beet nor maize or tuber crops are cultivated. The rotation is dominated by crops that mainly react positively to conservational tillage. Apart from these plant productive aspects that are expressed in the yield development, another effect of conservational tillage is more emphatically present in Finland than in other countries: conservational tillage consumes less gasoline. Gasoline efficiency is, in Finland, rewarded above the average, due to relatively high gasoline consumption rates per unit of crop (remember that EU-EFEM counts on region specific production cost estimates, including also fuel consumption). It more than compensates for a gasoline price which is below the EU-15 average. In the end, the monetarised fuel savings due to conservational tillage in Finland overweigh the fuel savings of other countries.

In view of the interregional variability found above, it is appropriate to also examine the intra-regional variability. The intra-regional variability is expressed in the simulated farms. Since the farms represent four farm types, it may be hypothesised that the simulated farms will also show different adaptation costs/gains to the scenario obligations/options.

Table 64: Change of GM in Scenario 1, Farm Level, Extreme Regions (to Reference Situation)

CVT- Min. Share	Scenario Case	Region	Farm Type			
			Arable	Forage	IntAnimal	Mixed
			(€/ha)			
0%	min00	Liège (Belgium)	7.27	12.24	5.74	9.30
40%	min40		7.27	12.24	5.74	9.30
70%	min70		1.22	12.24	5.49	7.75
100%	min100		-348.73	-61.31	-0.90	-293.81
0%	min00	Cologne (Germany)	0.12	1.55	--.--	0.65
40%	min40		-3.01	-1.30	--.--	-1.69
70%	min70		-15.56	-7.01	--.--	-6.48
100%	min100		-158.29	-65.12	--.--	-123.74
0%	min00	Itä Suomi (Finland)	27.41	27.72	27.32	27.91
40%	min40		27.41	27.72	27.32	27.91
70%	min70		27.41	27.72	27.32	27.91
100%	min100		18.14	24.28	22.81	19.42

The set hypothesis is confirmed for the three selected most extreme regions, Liège, Cologne and Itä Suomi. Their considerable intra-farm variability can be read from Table 64. In Liège, if 100% conservational tillage is forced, for example, the range of change of GM is from -349 €/ha to -1 €/ha roundabout. Recalling that the average loss in Liège was -260 €/ha (see Table 64), the deviation can be calculated as -89 to +259 €. Similar intra-regional variability is found in Cologne, with a deviation by -9 to +84 € from the average. However, in Itä Suomi the deviation is merely by -5 to +1 €.

From the above values it could be interpreted that forage growing and intensive livestock farms (“IntAnimal”) generally face lower losses/realise higher gains than arable or mixed farms. An argument against this would be in the larger share of high value cash crops, which are more vulnerable to the often negative yield impacts of conservational tillage. This interpretation, however, has not been soundly established, since only three (extreme) regions have so far been analysed.

On an EU-15 mean level, the separation line between farm types is not as marked and unambiguous as in the three regions above (see Table 65). In the cases ‘min40’ and ‘min70’, all farm types cope with the scenario obligations with the same ease. The difference between the highest and the lowest value stays below 2.50 €/ha. Only for case ‘min100’ do notable differences between the farm types crystallize. Then the arable farms loose 35 €/ha, while the forage growing farms only loose 3 €/ha rounded, a difference of 32 €/ha. The mixed farms and intensive livestock farms (‘IntAnimal’) are in between, with 21 €/ha respective 9 €/ha.

Table 65: Change of GM in Scenario 1, Farm Level, EU-15 (to Reference Situation)

CVT- Min. Share	Scenario Case	Region	**Farm Type**			
			Arable	**Forage**	**IntAnimal**	**Mixed**
				(€/ha)		
0%	min00		7.37	7.70	8.42	7.63
40%	min40	‘Mean’	7.00	7.53	8.14	7.35
70%	min70	(EU-15)	4.70	6.80	7.20	6.09
100%	min100		-34.53	-2.86	-9.37	-20.59

In summary, despite the fact that the tendencies are still noticeable, the large intra-regional variability found for the selected extreme regions is levelled out on an EU-15 mean level. The set hypothesis for the intra-regional variability is rejected. The levelling out can be partially explained by the way that the definition of farm types (in EU-EFEM based on a definition by the EU commission) is not the same for all regions (compare section 3.7).

4.3.3 Aggregated Regions: Economic and Ecological Results

In the former sections of the current scenario, a large intra-regional and interregional variability in economic impacts has been found. Both the intra-regional and the interregional variability only have been illustrated for selected extreme regions or in a condensed manner, as grouped results on GIS-maps. In the following, the interregional variability shall be stressed at the resolution of NUTS-I-regions, bringing down the number of regions from 136 NUTS-II regions to an acceptable number, and allowing deeper analysis of the topic. The intra-regional variability, i.e. farm level results, is not presented at a similarly high resolution because again around 100 data sets would be generated.

In Table 66, the change of the gross margin and the corresponding adoption rate of conservational tillage are opposed to each other and illustrated for NUTS-I-regions. In the scenario case with the strongest scenario obligations, in ‘min100’, economic losses are found in almost every country. Only in Sweden, Finland, and Luxembourg are no losses entailed. In the Netherlands, the loss is close to 100 €/ha and in the Belgium region Wallonne it even tops 140 €/ha. With respect to the adoption rate of conservational tillage, there are more than 10 NUTS-I-regions with shares of conservational tillage above 80% in all three scenario cases shown. In the Austrian region of Südösterreich, as much as 98% of conservational tillage is adopted. In contrast, in French NUTS-I-regions, the share is just the mandated minimum adoption rate of the corresponding scenario case.

Table 66: Impact of Scenario 1 on GM and CVT, EU-15 Average (to Reference Situation)

	Change of GM				Realised CVT				Change of GM				Realised CVT		
NUTS	0%	40%	70%	100%	0%	40%	70%	NUTS	0%	40%	70%	100%	0%	40%	70%
	(€/ha)				(% of arable)				(€/ha)				(% of arable)		
at1	8.66	8.44	6.06	-52.52	0.55	0.57	0.74	**def**	4.46	4.45	3.83	-15.60	0.53	0.54	0.70
at2	13.36	13.36	13.36	12.61	0.98	0.98	0.98	**deg**	2.99	2.74	-1.31	-20.88	0.38	0.42	0.70
at3	10.37	10.37	10.37	-0.92	0.86	0.87	0.87	**el1**	4.56	4.05	2.12	-6.34	0.46	0.57	0.72
be2	8.33	8.26	6.51	-42.43	0.68	0.69	0.73	**el2**	7.88	7.87	7.22	3.17	0.70	0.71	0.79
be3	8.93	8.93	5.09	-143.19	0.61	0.61	0.74	**el4**	11.54	11.54	10.48	4.91	0.74	0.74	0.76
dk0	14.36	14.36	14.36	-0.61	0.86	0.86	0.86	**ie0**	0.50	n.a.	n.a.	n.a.	0.41	n.a.	n.a.
fi1	21.33	21.33	21.33	9.40	0.88	0.88	0.88	**it1**	8.30	8.22	6.05	-4.44	0.42	0.47	0.70
fr2	0.69	-1.35	-5.08	-53.24	0.10	0.40	0.70	**it2**	19.86	19.86	19.29	-6.45	0.65	0.65	0.70
fr4	2.20	0.14	-4.32	-17.51	0.20	0.44	0.70	**it3**	12.10	12.10	12.08	-4.27	0.77	0.81	0.82
fr5	4.31	4.08	2.81	-5.84	0.38	0.46	0.70	**it4**	11.53	11.53	11.25	-24.77	0.71	0.71	0.74
fr6	3.60	3.60	3.40	-4.19	0.71	0.71	0.73	**it5**	13.73	13.73	13.73	1.06	0.80	0.80	0.80
fr7	6.44	6.43	4.98	-5.15	0.52	0.53	0.70	**it6**	11.78	11.78	11.78	6.75	0.86	0.86	0.86
fr8	7.80	7.80	7.24	0.95	0.73	0.73	0.77	**it7**	13.38	13.38	13.38	3.64	0.84	0.84	0.84
de1	4.71	4.49	3.59	-17.85	0.49	0.53	0.71	**it8**	12.02	11.98	11.91	9.01	0.79	0.80	0.83
de2	2.43	1.98	-0.22	-24.73	0.42	0.49	0.71	**it9**	14.04	14.04	14.04	9.66	0.90	0.90	0.90
de4	7.78	7.78	7.78	-2.85	0.86	0.86	0.86	**lu0**	4.82	4.82	4.82	3.68	0.83	0.83	0.83
de7	4.94	4.94	4.69	-42.92	0.59	0.61	0.72	**nl0**	13.46	13.43	4.67	-99.23	0.62	0.63	0.76
de8	3.40	3.40	3.21	-20.04	0.57	0.57	0.73	**pt1**	10.08	10.08	9.11	-3.55	0.63	0.63	0.72
de9	2.56	1.41	-2.43	-83.79	0.27	0.48	0.71	**es1**	8.20	8.14	7.92	6.17	0.60	0.62	0.77
dea	4.14	3.24	-0.15	-67.43	0.36	0.50	0.72	**es2**	2.32	2.18	1.26	-6.90	0.27	0.48	0.70
deb	1.54	1.19	-1.48	-29.28	0.34	0.43	0.70	**es4**	8.63	8.63	8.62	-2.23	0.48	0.76	0.76
dec	9.84	9.84	9.83	4.54	0.74	0.74	0.76	**es5**	7.12	7.10	6.88	0.53	0.63	0.65	0.73
ded	3.11	2.48	0.76	-26.33	0.38	0.49	0.70	**es6**	5.99	5.98	5.87	-10.72	0.58	0.59	0.71
dee	4.04	3.99	3.59	-28.98	0.65	0.68	0.76	**se0**	16.56	16.56	16.55	1.85	0.84	0.84	0.84

Looking at the scenario results on the average[72] level of the EU-15, it can be seen that it is only the obligation to rededicate 100% of arable land to conservational tillage that entails economic losses (see Table 67). Then the loss gets close to 20 €/ha. In forcing lower shares, scenario gains are realised that gradually decrease from 7.32 €/ha ('min00') to 5.48 €/ha ('min70'). This phenomenon is hardly surprising, since conservational tillage apart from its contribution to SOC accumulation it is also a means to reduce tillage costs in many regions. This is confirmed by final conservational tillage shares exceeding the forced shares: 56% in 'min00', 63% in 'min40', and 75% in 'min70' (logically not in case 100% are forced). It is only for conservational tillage shares above 80% that the average gross margin decreases (not depicted in the table). Up to this threshold the gross margin increases with the scenario.

Table 67: Impact of Scenario 1, EU-15 Average (to Reference Situation)

		CVT Minimum Share			
Item	**Unit**	**0%**	**40%**	**70%**	**100%**
Gross Margin	(€/ha)	7.32	6.90	5.48	-19.60
Conservational Tillage	(fraction)	0.56	0.63	0.75	1.00
Soil Organic Carbon	(t/ha)	0.002	0.001	0.002	0.032

From an ecological or better climate perspective, the scenario achieves merely very slight improvements. During the scenario's conception phase, it had been hypothesised that conservational tillage (less soil disturbance, partially higher organic matter input) proportionally and significantly expresses in increasing SOC accumulation rates. However, even under 100% conservational tillage the SOC accumulation is only 0.004 t/ha equal to a mitigation of 0.032 t/ha, i.e. a difference of 0.028 t/ha between negative accumulation (freeing) in the reference situation of -0.028 t/ha and the accumulation in the scenario case (see Table 67). The overwhelmingly low rate of SOC-accumulation is partially due to the higher negative and positive accumulation rates of single regions levelling out against each other on the described EU-15 average. The regional accumulation rates are from -0.890 t/ha (highest freeing) to +0.760 t/ha (highest mitigation) (compared to the reference situation).

---

[72] Remember that here the term 'average' is seen as weighted average in contrast to 'mean' which is non weighted average values.

Table 68: Summarised Impacts of Scenario 1, EU-15 Level

Item	**Unit**	**REF**	**Min00**	**Min40**	**Min70**	**Min100**
SOC Accumulation	(1000t)	-888.7	-825.5	-867.9	-810.8	121.6
Δ-SOC Accumulation*	(1000t)	-.-	63.2	20.8	77.9	1010.3
Δ-GM*	(Mill €)	-.-	392.9	370.4	294.2	-1052.5

Aggregating SOC-accumulation rates for all analysed regions, on the **EU-15 average level** 121.6 t of SOC could be accumulated per year (see Table 68). The mitigation (avoided freeing from the baseline[73] 'min00' plus accumulation under the scenario) could reach 947,100 t of SOC (825.5 t plus 121.6 t). The mitigation of 947,100 t of SOC corresponds to 3,472,300 tCO_2e. But the preceding rates are only achieved if 100% of arable land is rededicated to conservational tillage. The change of the gross margin for this case is -1,052.5 Mill €. Dividing the mitigated tons of CO_2-equivalents by the change of GM, the mitigation costs would calculate as over 280 €/tCO_2e.

4.3.4 Critical Remarks

In the current scenario, the economic and ecological impacts from the obligation to dedicate certain shares of arable land to conservational tillage were analysed. In this analysis, a critical view on the assumptions made might be appropriate.

In first place, it is a rather unrealistic assumption that farmers would dedicate only shares of their arable land to conservational tillage. This implies that both types of tillage equipment are available at farms, for both conventional and conservational tillage. The adversely high fixed costs of conventional tillage technology and especially of no-till technology make this improbable. But it can be countered that farmers have the choice to outsource tillage or harvest activities.

In second place, it is the exclusion of conservational tillage from the reference situation in EU-EFEM to which the scenario's results were compared. In reality, however, conservational tillage has become rather popular in some of the EU-15 member states. Mulch seeding in particular is practised, and overall share of conservational tillage has reached 25% of arable land (compare Table 19). If freely allowed, EU-EFEM simulates a share of 56% of conservational tillage (corresponding to scenario case 'min00'). Taking this as initial point, the economic impacts of the

---

[73] 'Min00' seemed to reflect reality better than the reference situation since conservational tillage is free of choice.

scenario level out, and the gains shown above would be worse by 7.32 €/ha (this derogation corresponds to the average additional gross margin when allowing for conservational tillage (see Table 67).

In third place, in conjunction with ecological impacts, it should be repeated that SOC-accumulation (not SOC-mitigation) assumes a permanent switch to conservational tillage. In reality, formerly accumulated SOC is released quickly if farmers return to conventional tillage even if only it was for a single production period.

With respect to the economic results, the following remarks should be appended. In advance of scenario 1, gross margins in switching from conventional to conservational tillage were compared, but only on a single crop level, and disregarding the farms' conditions (see Table 53). It was without optimising the simulated farms in EU-EFEM and thus without considering farm internal adaptation measures like rotational changes. Compared to this situation, the results of scenario 1 suggest large intra-farm adaptability, since economic losses due to the switch are by far lower. Additionally, a second context was made apparent with scenario 1: economic impacts also vary between farm types. This is due to the effect of labour costs. They have the potential to balance losses since conservational tillage practices are generally less labour intensive (no-till saves up to 2 h/ha). This ultimately means that depending on the subjective definition of opportunity costs of labour by farm holders, the economic impact of switching to conservational tillage will deviate from the regional average impact.

Scenario 1 predicted scenario gains for the majority of farms for the slightest scenario obligation of 40% minimum conservational tillage share. This is not surprising, since in a free market situation the average share of conservational tillage reached 56% (compare CVT share in 'min00'). In all scenario cases, however, regions or single farms without a valid solution were excluded from drawing the average and mean values. This might entail strong biases, but it was the only passable way[74].

The impact of tillage equipment and labour costs on the economic impact of the switch to conservational tillage has already been mentioned. The largest factor in the

---

[74] Taking the gross margin per hectare from the reference situation as scenario costs for these cases could be considered, but this seems too rough an approximation.

overall economic impact is nonetheless often enough the yield impact (simulated by EPIC) on which the scenario is based. In such cases where the yield impact dominates the scenario impact, scenario’s results are made highly sensitive to changes in sales prices of crops. Since, with a few exceptions, the yield impact of conservational tillage is negative, higher prices will lead to higher losses (respective lower gains) and vice versa. In comparison to the reference year 2003, on one hand sales prices generally have increased, which would mean that conservational tillage has become less attractive since then. On the other hand, guaranteed quota prices of sugar beet have been reduced so that the overall attractiveness of conservational tillage against 2003-level would have to be analysed for single farms again.

4.4 Scenario 2: Mandatory SOC-Accumulation

The scenario 1 is based on the values of the reference situation, i.e. of the year 2003. In scenario 2, similar to scenario 1, a way to stimulate SOC-accumulation is sought. It is motivated by the disappointingly low SOC-accumulation rates of scenario 1. Higher accumulation rates will definitely be achieved since they are forced. Therefore, scenario 2 is denominated “Mandatory SOC-Accumulation”. The simulated farms are offered several measures to achieve the forced rate whereof the model chooses the single optimal measure or the optimal combination of measures. It is hypothesised that through the freedom to select among scenario measures, mitigation costs will be lower than in scenario 1 with the single measure conservational tillage.

In detail, scenario 2 obliges farmers to accumulate a certain amount of SOC (annually) on their arable land. Grassland is exempted even though it could substantially contribute, especially in the case of land-use change from arable land to grassland, but the latter is not an option in EU-EFEM. The scenario considers the following two cases of mandatory yearly SOC-accumulation rates on arable land:

(1) SOC05: SOC-accumulation of at least 0.5 t/ha, and

(2) SOC10: SOC-accumulation of at least 1.0 t/ha.

The scenario's eligible measures compose of:

(1) Modification of crop rotation, e.g. to more humus accumulating cultures,

(2) Adoption of conservational tillage,

(3) Increase of humus input from plant biomass[75], e.g. straw left to decay on fields,

(4) or Combination of measures (1) - (3).

The theoretical background on the scenario's measures was given in section 2.3.1. For conservational tillage the same constraints as under scenario 1 apply, i.e. the relation between no till and mulch seeding must not exceed 1:2. The yield impacts modelled by EPIC are based on all management alternatives. As long as no rotational restrictions are violated, farmers are free to decide on the crop mix.

Furthermore, 'min00' of scenario 1 is appended as a baseline for comparison purposes where useful. In 'min00', conservational tillage is free of choice, yet no biasing scenario obligations are active.

The above restrictions are effective on a farm level. Results will be presented on a farm, on a regional, and on an EU-15 average and mean level. On farm level all farms with a valid solution are presented. On a regional level and on an EU-15 mean level, only regions in which all represented farms show a valid solution are presented. On an EU-15 average level, only regions where for all farms and for all scenario cases a valid solution is returned by the model are included.

The ecological (climate) assessment of the scenario spares to the widest extent since impacts are predefined by the forced SOC accumulation rates. Only marginal positive deviations because of the over-accomplishment of forced SOC accumulation rates are found, on one hand. On the other hand, because of "non-optimal solutions" for some simulated farms, negative deviations occur.

4.4.1 Regionalized Results

The ecological impacts, here understood as the amount of SOC accumulated annually, are predefined, since the SOC accumulation rate is constrained by the scenario. The indicator for the economic scenario impacts is again the "change of

---

[75] Neither winter catch crops nor organic carbon from manure are considered. The latter is disregarded since no explicit EPIC simulation was available.

gross margin". Because of the specific illustrative advantages already mentioned, a first overview over the study region will be created with GIS maps. This makes the grouping of single farm results indispensable. In Figure 17 the change of gross margin in the case of mandated 0.5 t SOC/ha ('SOC05') accumulation is illustrated.

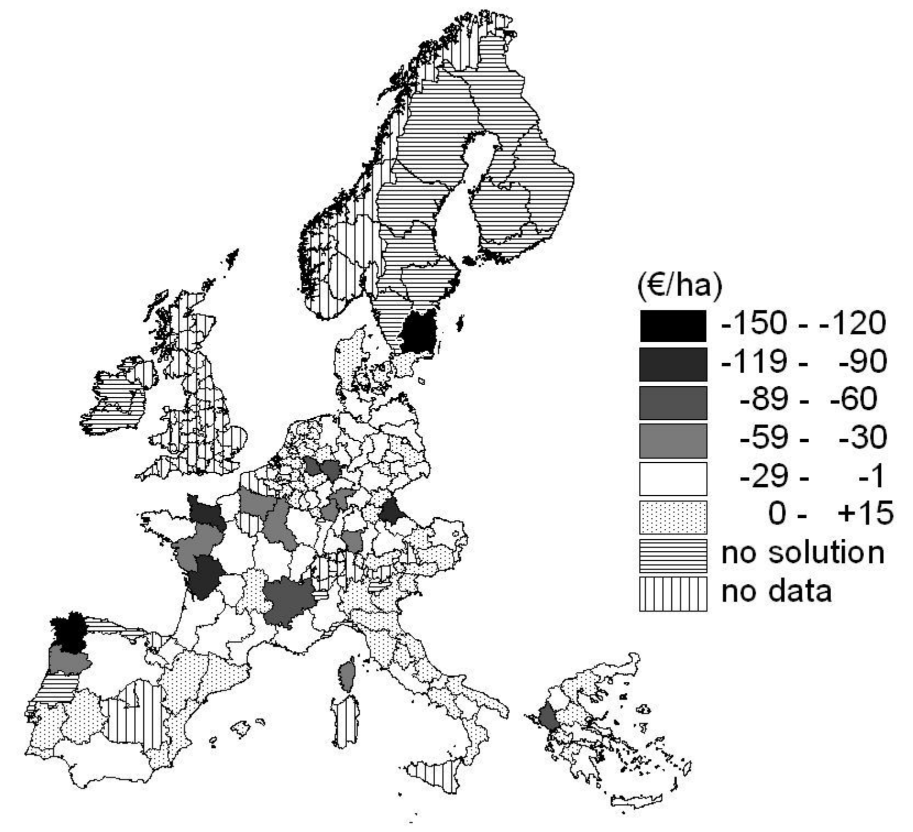


Figure 17: Change of Gross Margin in SOC05 (to Reference Situation)

The highest positive change of GM is 15 €/ha, the highest negative change is 150 €/ha. The potential to realise a scenario gain is due to the fact that for the scenario conservational tillage is allowed, while for the reference situation it is not. The group of regions that realise slight scenario gains is the largest. Together with the group that realises minor losses, between 1 and 29 €/ha, they form the majority. Losses of 30 €/ha and above are more rare and only found in a few regions. Nevertheless, the maximum loss of 150 €/ha is substantial. Some regions, 17 in number, are even worse off since they cannot comply with the scenario obligations at all, i.e. the mandated accumulation rate is unachievable.

In Figure 18 the change of GM is illustrated for the case of 1.0 t SOC/ha minimum accumulation ('SOC10'). Although already fewer in number, still a notable amount of regions realises scenario gains that still can be as high as 15 €/ha, but are predominantly settled between 3 and 5 €/ha. These regions are concentrated in Southern European countries. At the same time, 25 regions cannot comply with the scenario obligations. These regions are predominantly in Finland, Sweden, and Ireland. In these three countries, a valid solution is returned only for one single region. Many other regions across the EU-15 suffer from a decrease in GMs between 50 and 100 €/ha. The maximal loss found is close to 250 €/ha, which is nearly twice as much as under case 'SOC05'.

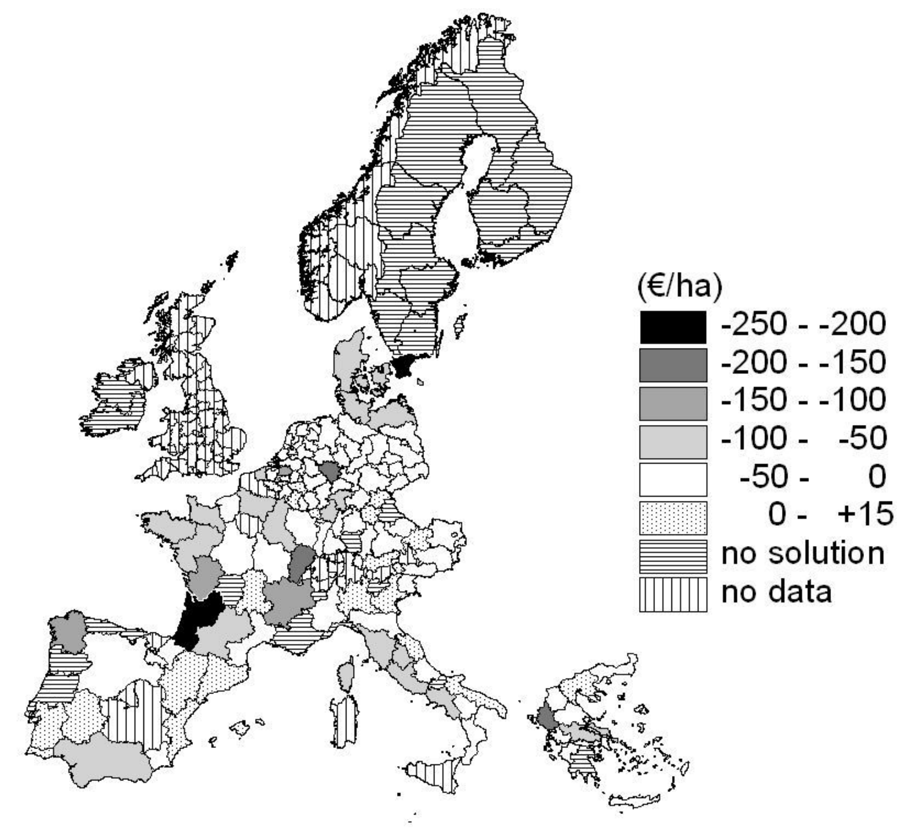


Figure 18: Change of Gross Margin in SOC10 (to Reference Situation)

The wide interregional variability has already been mentioned and can also be read from the grouped results depicted in the above GIS-maps. In Table 69 the interregional variability is confirmed, but can be read in exact values, although only for NUTS-I-regions in order to not overload the illustrative means. The range is from -127.91 to 11.54 €/ha in scenario case 'SOC05' and from -225.96 to 6.93 €/ha in scenario case 'SOC10'. The ranking of the regions thereby changes substantially between 'SOC05' and 'SOC10'.

Table 69: Economic Impacts of Scenario 2, NUTS-I-Level

NUTS-I	SOC05	SOC10	NUTS-I	SOC05	SOC10
	(€/ha)			(€/ha)	
at1	-6.50	-14.99	**def**	-12.06	-62.86
at2	11.01	-3.94	**deg**	-8.91	-11.44
at3	5.59	1.93	**el1**	-1.91	-11.33
be2	-10.07	-41.30	**el2**	-11.38	-37.20
be3	6.41	2.04	**el4**	-4.73	-6.29
dk0	2.06	-69.22	**ie0**	n.a.	n.a.
fi1	n.a.	n.a.	**it1**	-24.73	-31.03
fr2	-28.90	-35.11	**it2**	2.23	2.23
fr4	-8.25	-58.06	**it3**	9.45	-9.95
fr5	-67.11	-85.71	**it4**	4.71	-3.38
fr6	-10.31	-152.18	**it5**	11.54	-48.09
fr7	-31.97	-45.96	**it6**	-0.82	-98.75
fr8	-5.81	-25.66	**it7**	3.19	-12.48
de1	-15.91	-26.95	**it8**	6.95	-80.17
de2	-16.07	-9.02	**it9**	4.03	-13.39
de4	-0.29	-39.36	**lu0**	-7.69	-4.72
de7	-20.80	-40.86	**nl0**	7.31	-2.12
de8	-6.98	-62.19	**pt1**	5.73	6.93
de9	-16.37	-38.47	**es1**	-127.91	-128.73
dea	-36.37	-54.64	**es2**	-3.20	-13.24
deb	-26.13	-34.91	**es4**	-3.05	-11.40
dec	5.48	4.94	**es5**	6.18	4.83
ded	-9.34	-11.71	**es6**	-3.48	-39.71
dee	-1.72	-13.11	**se0**	-77.94	-225.96

4.4.2 Selected Regions: Economic Results

The previously found wide interregional variability of economic impacts begs the question of their intra-regional variability. The latter expresses in the single units constituting a region in EU-EFEM, the simulated farms. The farms are looked at, similar to scenario 1, for the most extreme regions. This is to create an impression of the whole range of farm results across all analysed regions. With respect to the economic impacts, the most extreme regions are considered here as those with the highest positive and negative regional change of farms' gross margins. These two regions do not necessarily contain the single most extreme changes of gross margins of farms.

Table 70: Change of GM in Scenario 2, Farm Level, Extreme Regions, (to Reference Situation)

SOC-Minimum Accumulation	Region	Farm Type Arable	Forage	IntAnimal	Mixed
		(€/ha)			
0.5 t (SOC05)	Aquitaine (France)	-13.05	-16.49	-65.01	-15.73
1.0 t (SOC10)		-369.23	-136.35	-84.10	-199.08
0.5 t (SOC05)	Puglia (Italy)	15.20	15.65	15.37	15.58
1.0 t (SOC10)		14.47	14.79	14.50	14.86

The region with the highest negative change of gross margin is Aquitaine (France) and the region with the highest positive change is Puglia (Italy) (see Table 70). In Aquitaine the change of GM due to the forced accumulation of 0.5 t SOC oscillates around -15 €/ha for the arable, forage and mixed farm. For the intensive livestock farm ('IntAnimal') the change is around -65 €/ha. If the forced accumulation is increased to 1.0 t, the losses increase significantly and also the ranking of the farms changes. Then the intensive livestock farm comes off best with a change of GM of around -84 €/ha while the maximal change is for the arable farm with nearly -370 €/ha. This means for the scenario cases an intra-regional variability of 52 €/ha for 0.5 t SOC accumulation and around 285 €/ha for 1.0 t SOC accumulation. Looking at Puglia, the region with the highest positive change of GM, there are no notable differences between the farms, i.e. the intra-regional variability is very low, and does not exceed 1 €/ha. Further, the scenario case does not affect the structure of results in Puglia. All farms show an increase of GM of around 15 €/ha.

Table 71: Change of GM in Scenario 2, Farm Level, EU-Mean (to Reference Situation)

SOC-Minimum Accumulation	Region	Farm Type Arable	Forage	IntAnimal	Mixed
		(€/ha)			
0.5 t (SOC05)	"Mean (EU-15)"	-16.03	-9.25	-21.00	-14.59
1.0 t (SOC10)		-41.45	-28.26	-39.04	-30.85

Table 71 shows the EU-15 mean values for the change of gross margin under the scenario. The doubling of the minimum SOC accumulation rate from 0.5 t to 1.0 t roughly doubles the losses of GM. Forcing an accumulation of 0.5 t the losses are roughly between 10 and 20 €/ha. At the forced SOC accumulation of 1.0 t, the losses are between 30 and 40 €/ha. Thus, even on the mean level an intra-regional variability (10 €/ha for SOC05 and 10 €/ha for SOC10) persists.

4.4.3 Selected Regions: Adoption Rate of Scenario Measures

The current scenario with the forced minimum SOC accumulation rates for arable land offers the farms four scenario measures. A uniform reaction or a uniform combination of measures is not found. Farm structures, regional production costs, regional yields and yield impacts are too diverse to push farms in only one direction.

The illustration of the scenario measures' adoption rate would be too expensive if pursued for all single analysed regions. That is why results are only illustrated for a selection of most extreme regions in the following. Extreme regions were selected with respect to the adoption rates of the scenario measures. The extreme regions identified in that way are in Spain, Portugal, France, Belgium, and Greece.

Measure (1): *"Modification of Crop Rotation"*

Galicia (ES11): Strongest reduction in tuber crops and largest share of other non-cereals[76] (in SOC05)

Alentejo (PT18): Lowest share of other non-cereals (in SOC05)

Rhône-Alpes (FR71): Strongest reduction in other non-cereals

Measure (2)*: "Switch to Conservational Tillage"*

Ipeiros (GR21): Strongest reduction in conservational tillage

Bretagne (FR52): Strongest increase in conservational tillage

Measure (3): *"Humus Input from Plant Biomass"*

Limburg (BE22): Strongest reduction in straw for decay on field

It is assumed that the adoption rate of the measure (4), "*Combination of measures (1) - (3)*", is highest and is therefore illustrated first (see Table 72).

---

[76] Non-cereals other than maize or tuber crops

Table 72: Combined Adoption of Measures in Scenario 2, Case SOC05, Extreme Regions

		Crop Mix				Tillage	Straw Decay		
Reg	**Case**	**CER**	**MAZ**	**ONC**	**TUB**	**CVT**	**Field**	**Share**	**SOC**
		(%)				(%)	(t/ha)	(%)	(t/ha)
ES11	REF	37.8	40.4	11.4	10.4	62.4*	0.90	43.9	0.00
	SOC05	12.5	29.4	51.3	6.8	57.5	0.67	56.9	0.50
PT18	REF	86.6	12.0	0.0	1.4	57.0*	1.85	71.4	-0.01
	SOC05	86.3	12.0	0.3	1.4	57.3	2.02	78.4	0.50
FR71	REF	40.9	21.3	37.3	0.5	57.7*	3.68	62.6	0.00
	SOC05	43.7	28.7	27.1	0.5	82.2	4.07	80.3	0.50
BE22	REF	64.9	12.5	10.0	12.6	75.0*	8.07	65.7	-0.10
	SOC05	66.8	10.3	10.2	12.6	81.0	2.43	37.8	0.50
GR21	REF	56.8	43.2	0.0	0.0	74.5*	1.50	51.6	-0.52
	SOC05	19.8	50.1	27.8	2.4	52.1	1.76	83.0	0.52
FR52	REF	52.3	10.6	35.9	1.1	16.9*	2.38	47.8	0.00
	SOC05	52.6	5.9	40.4	1.1	79.6	3.00	63.7	0.50

**This share is not from the reference situation, but from min00-scenario 1.*

In Galicia (ES11) the increase of humus accumulating crops is the preferred measure. Out of all regions, Galicia shows the highest increase in other non-cereals (by 39.9%-points) and the strongest decrease in tuber crops (by 3.6%-points) in comparison to the reference situation. It appears that this reaction combines well with the increase of plant biomass input to the soil: instead of 43.9% in the reference of accruing straw 56.9% are left for field decay in SOC05. The least competitive measure in Galicia is conservational tillage, which is reduced by 4.9%-points.

In Alentejo (PT18) the increased cultivation of humus accumulating crops is only adopted marginally and also the extent of conservational tillage sticks to the level of the reference situation. The only measure taken here is increasing the level of straw left for field decay. Yet also this measure is adopted only weakly. It appears that the slight changes suffice to satisfy the forced minimum SOC accumulation of 0.5 t/ha of SOC05.

In Rhône-Alpes (FR71) the most competitive reaction to the scenario obligation is a combination of conservational tillage and straw for field decay. Both measures are taken up to a significant degree and are increased significantly above the reference level. Through doing this, a sufficient margin for reducing other non-cereals in the crop rotation is left. Rhône-Alpes is even the region with the strongest decrease of other non-cereals.

In Limburg (BE22) the share of straw left for field decay is decreased to the greatest level. At the same time, the adoption of the other measures is only slightly increased. However, in Limburg rather high shares of tuber crops are cultivated. Since these react relatively strongly to straw residues left on the field with decreased yields, here it seemingly pays to reduce the amount of straw left for field decay.

In Ipeiros (GR21), in contrast, the strongest increase of the measure "straw for field decay" occurs, concretely, by 31%-points. Also the modification of the crop rotation in favour of humus accumulating crops is very strong, leaving room for simultaneously increasing shares of maize. The combination of increased levels of straw left for field decay with higher shares of other non-cereals against more maize in the rotation had already been found in Galicia (ES11) and seems to be competitive.

In Bretagne (FR52), finally, the degree of adoption of conservational tillage is the strongest found with an increase by 62.7%-points. Despite this strong adoption it is combined with the other measures. Green leaf crops are increased by 4.5% (at the expense of maize) and straw left for field decay is increased by 15.9%-points.

Table 73: Change of GM in Scenario 2, Case SOC05, Extreme Regions (to Reference)

Region (Code)	**Change GM** (€/ha)	**Region**	**Change GM** (€/ha)
Galicia (ES11)	-127.91	Limburg (BE22)	3.17
Brabant-Wallon (BE31)	5.04	Ipeiros (GR21)	-81.31
Alentejo (PT18)	6.26	Bretagne (FR52)	-25.82
Rhône-Alpes (FR71)	-83.78		

Although in each of the selected extreme regions, farms seemingly found their proper adaptation strategy to the scenario obligations, the economic impact farms face in that way is expected to be diverse. This is confirmed when looking at the change of gross margin in the regions, illustrated in Table 73. It could be interpreted that those regions with the strongest rotational adaptations (Galicia, Rhône-Alpes, and Ipeiros) are the regions with the highest scenario costs. That is even true for Rhône-Alpes, where a strong shift occurs towards the rather profitable production of maize which seemingly could not compensate for the negative impact of the other rotational changes. The highest decrease of GM is found in Galicia, the region with the highest decrease in tuber crops, a crop type featuring an extraordinarily high GM.

In the other regions where the two measures other than crop rotational changes are stressed, the decrease of GM is by far lesser, or even scenario gains take place.

4.4.4 Aggregated Regions: Adoption Rate of Scenario Measures

It would now be interesting to find out about the single contribution of the four available scenario measures, thereby facilitating the interpretation of results. The illustration of the respective adoption rates of measures cannot be performed on farm level and for each study region because of the sheer amount of data. Therefore, the results will only be presented and discussed here on the NUTS-I-level, an aggregation of the NUTS-II-level which is the study regions. For the three economically most and least affected NUTS-I-regions the adoption of measures shall first be described briefly.

The three most (negatively) affected NUTS-I-regions in scenario case SOC10 are SE0 (Sweden), ES1 (Noroeste, Spain), and FR6 (Sud-Ouest, France):

- In SE0 the share of conservational tillage with 95% is close to the upper limit. Measure (1), "*Modification of Crop Rotation",* is strongly implemented with the cereals in the crop rotation being widely replaced by non-cereals other than maize and tuber crops (so denominated ONC crops). These reactions are in line with expectations and assumingly contribute to SOC-accumulation. However, the share of straw left for field decay in SE0 is only at 19%.
- In ES1 the share of conservational tillage with 72% is moderate while the adoption of measure (1) is strong with the share of ONC being increased by 40%-points.
- In FR6 the share of conservational tillage is low, the share of straw that is left for field decay is only 58% of the baseline, and although the share of cereals in the crop rotation is decreased, the share of non-cereals other than maize or tuber crops (ONC) does not go up. All these reactions are not the measures typically contributing to SOC-accumulation.

The three least affected regions in scenario case SOC10 are PT1 (Continente, Portugal), DEC (Saarland, Germany), and ES5 (Este, Spain). In all three regions the straw management and the crop rotation are only minimally changed. Conservational tillage is slightly expanded over the shares in the baseline (the baseline is ‘min00’). So, in these three regions seemingly none of the available measures helps complying with the forced minimum SOC-accumulation rate.

In Table 74 the adoption of measures in scenario 2 and the economic impacts thereof are shown for all NUTS-I-regions. The economic impacts on the three most affected regions is -226 €/ha in SE0, -152 €/ha in FR6, and -129 €/ha in ES1. In contrast the three least affected regions even realise slight scenario gains being from 5 €/ha in DEC and ES5 to 7 €/ha in PT1. Since there are only three further regions where scenario gains below 5 €/ha can be realised it is evident that negative economic impacts of scenario 2 dominate with losses being higher than 10 €/ha in the majority of regions.

Table 74: Adoption of Measures in Scenarion 2, Case SOC10, NUTS-I-Level

Nuts-I	GM	CVT*	Straw**	Cereals	ONC*	Nuts-I	GM	CVT*	Straw**	Cereals	ONC*
	(€/ha)	(fraction)	(ratio)	(fraction)	(fraction)		(€/ha)	(fraction)	(ratio)	(fraction)	(fraction)
at1	-14.99	0.49	2.85	-0.10	0.00	**def**	-62.86	0.72	1.12	-0.23	0.19
at2	-3.94	1.00	1.98	-0.02	0.02	**deg**	-11.44	0.50	0.97	0.05	-0.07
at3	1.93	0.92	0.98	0.02	-0.02	**el1**	-11.33	0.67	1.24	-0.07	0.09
be2	-41.30	0.76	0.82	-0.02	0.10	**el2**	-37.20	0.78	0.88	-0.14	0.06
be3	2.04	0.64	0.97	-0.04	0.04	**el4**	-6.29	0.81	1.01	-0.10	0.16
dk0	-69.22	0.86	0.81	-0.15	0.05	**ie0**	n.a.	n.a.	n.a.	n.a.	n.a.
fi1	n.a.	n.a.	n.a.	n.a.	n.a.	**it1**	-31.03	0.47	0.94	-0.15	0.14
fr2	-35.11	0.42	1.10	-0.05	0.08	**it2**	2.23	0.62	1.04	-0.08	0.04
fr4	-58.06	0.15	0.96	-0.07	-0.01	**it3**	-9.95	0.85	1.37	-0.07	0.08
fr5	-85.71	0.48	1.06	-0.13	0.11	**it4**	-3.38	0.86	1.59	-0.05	0.02
fr6	-152.18	0.50	0.58	-0.14	-0.07	**it5**	-48.09	0.73	1.25	-0.19	0.22
fr7	-45.96	0.49	0.93	-0.08	0.09	**it6**	-98.75	0.69	0.67	-0.11	0.27
fr8	-25.66	0.90	1.49	-0.08	0.02	**it7**	-12.48	0.98	1.01	0.00	
de1	-26.95	0.61	0.85	-0.15	0.10	**it8**	-80.17	0.64	0.76	-0.17	0.33
de2	-9.02	0.52	0.86	-0.02	0.01	**it9**	-13.39	0.75	0.82	-0.15	0.18
de4	-39.36	0.85	1.46	0.07	-0.07	**lu0**	-4.72	0.85	1.36	-0.04	0.00
de7	-40.86	0.54	1.07	-0.12	0.03	**nl0**	-2.12	0.64	0.65	-0.01	-0.03
de8	-62.19	0.87	1.70	-0.14	0.07	**pt1**	6.93	0.63	1.00	-0.01	0.01
de9	-38.47	0.57	0.69	-0.02	-0.04	**es1**	-128.73	0.72	0.70	-0.25	0.40
dea	-54.64	0.57	1.19	-0.12	0.08	**es2**	-13.24	0.73	1.29	-0.06	0.06
deb	-34.91	0.29	1.08	-0.11	0.04	**es4**	-11.40	0.89	1.10	-0.05	0.06
dec	4.94	0.78	0.75	0.09	-0.08	**es5**	4.83	0.74	1.04	-0.01	0.01
ded	-11.71	0.30	1.00	-0.01	-0.03	**es6**	-39.71	0.54	0.84	0.07	0.00
dee	-13.11	0.74	1.32	0.00	0.00	**se0**	-225.96	0.95	0.19	-0.19	0.19

**CVT: Conservational Tillage; ONC: non-cereals other than maize and tuber crops.*

***Change of straw left for field decay.*

Leaving this NUTS-I-level, it is first interesting to get an overview of the general adoption of the scenario measures. In the EU-15 the measure (4), *"Combination of measures (1) - (3)"*, is supposedly the most adopted measure. This is also confirmed by the results illustrated in Table 75. The "combination of measures" is adopted in 62.0% of regions under 'SOC05' and in 75.2% under 'SOC10'. The table reveals that also the remaining measures are quite popular. In 33.9% of regions under 'SOC05' and in 23.0% under 'SOC10', only a single measure is applied. This measure is not the same for all relevant regions. Rather each of the three measures is found adopted as a single measure. A generalization on the preference of a single measure thus cannot be made.

Table 75: Summarised Adoption of Measures in Scenario 2, EU-15 Level

ID	**Adoption**	**SOC05**	**SOC10**
		(%)	
1	no measure	4.1	1.8
2	one single measure	33.9	23.0
3	combination of measures	62.0	75.2
4	Crosscheck (1+2+3)	100.0	100.0
5	measure 1*: increased share of non-cereals	43.0	52.6
6	measure 2: increased share of conservational tillage	70.2	68.1
7	measure 3: increased share of straw for decay on field	66.9	85.8

**: Originally the measure is "modification of crop rotation e.g., to humus accumulating crops".*

The first measure, *"modification of crop rotation",* can be an adequate reaction to the scenario obligations if more "humus effective" cultures are pushed at the expense of "humus ineffective" ones. Taking into account the economic dimension, such cultures with an optimal relation between gross margin and humus (SOC) accumulation should be preferred.

It is found that on average the modification of crop rotations is only weak in the EU-15 (see Table 76). Under 'SOC05' 2%-points more non-cereals other than maize or tuber crops (abbreviated "ONC") are produced at the expense of cereals compared to the reference situation. Under 'SOC10' ONC is increased by 6%-points, all at the expense of cereals and maize replaces 2%-points of cereals. In both scenario cases, the share of tuber crops remains unaffected. This suggests that the opportunity cost of taking tuber crops out of production is too high in comparison to taking out cereal crops.

Table 76: Crop Rotation in Scenario 2, EU-15 Average

Case	Region	Cereals	Maize	ONC	Tuber
			Crop Group		
			(fraction)		
REF		0.58	0.11	0.26	0.05
SOC05	“Average (EU-15)”	0.56	0.11	0.28	0.05
SOC10		0.50	0.13	0.32	0.05

Despite this clear tendency to stress other non-cereals at the expense of cereals, this reaction is not uniformly found in all regions. It is more likely that all possible changes of crop rotation are found in the single regions. Cereal shares are increased and decreased, maize shares are increased and decreased, and the same for other non-cereals (“ONC”). The share of tuber crops is the only constant in all regions, with very few exceptions.

The second measure, *adoption of conservational tillage*, is implemented at different degrees across the EU-15. Figure 19 shows the change of the share of conservational tillage under the 1.0 t minimum accumulation (‘SOC10’): The change is related to the baseline (‘min00’ of scenario 1) where conservational tillage is free of choice but no accumulation is enforced. The scenario obligations provoked a somehow unexpected reaction: in some regions farmers reduce the share of conservational tillage below the shares of the reference situation. If taking conservational tillage as single measure, there is no reason to decrease its share below that of the baseline, which is an economic optimum free from any scenario obligations.

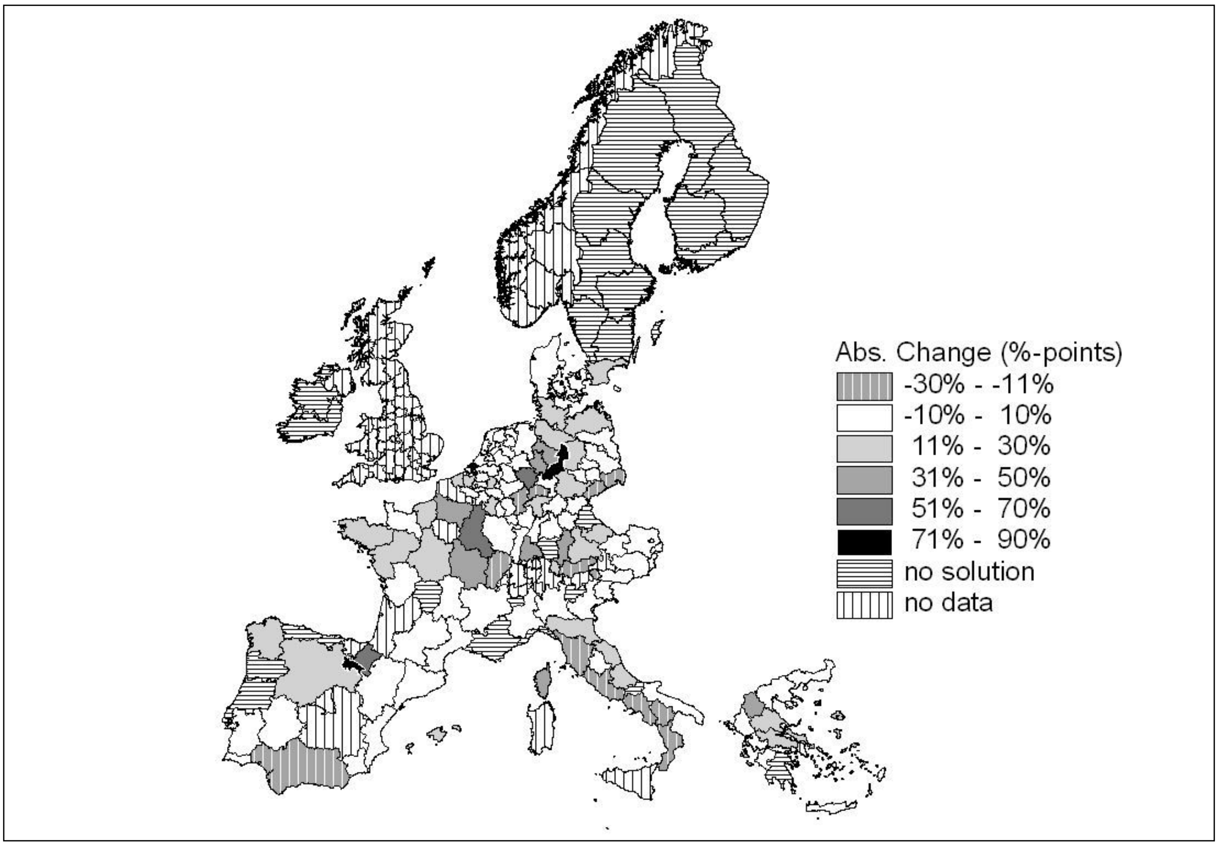


Figure 19: Conservational Tillage Share of SOC10 compared to min00

Although the decreases in conservational tillage in comparison to the baseline are slight, they can be confirmed for more than 30 regions. It is seemingly the combination of several measures and their interaction with conservational tillage that diminishes its rate of adoption. In the regions where this phenomenon occurs the following constellations prevail. First, the competitiveness of the modification of the crop rotation and/or the increase of humus input from plant biomass is higher. Second, the impact of conservational tillage on one or both of these measures is negative. The latter can rear from EPIC's yield simulations. The simulations suggest an intensified negative yield reaction in case all straw is left on the field. Especially for cultures with large amounts of straw or cultures with strong requirements on well-prepared seedbeds, additional straw cover impedes germination and in consequence affects yield. Thus, if additional straw left for field decay is the most humus efficient measure, it might be an appropriate scenario reaction to simultaneously decrease shares of conservational tillage.

Despite the decrease in conservational tillage to below baseline levels in more than 30 regions, conservational tillage appears to remain an adequate measure to increase SOC-accumulation. In two regions (Braunschweig, Germany and La Rioja, Spain) the increase of conservational tillage is huge and falls in the group of 71%- to 90%-points increase (Figure 19). The remainder regions can be classified into two majority groups. In one the degree of conservational tillage remains nearly unaffected (-10%-point to +10%-points). In the other notable increases between +10%-points and 30%-points can be noticed.

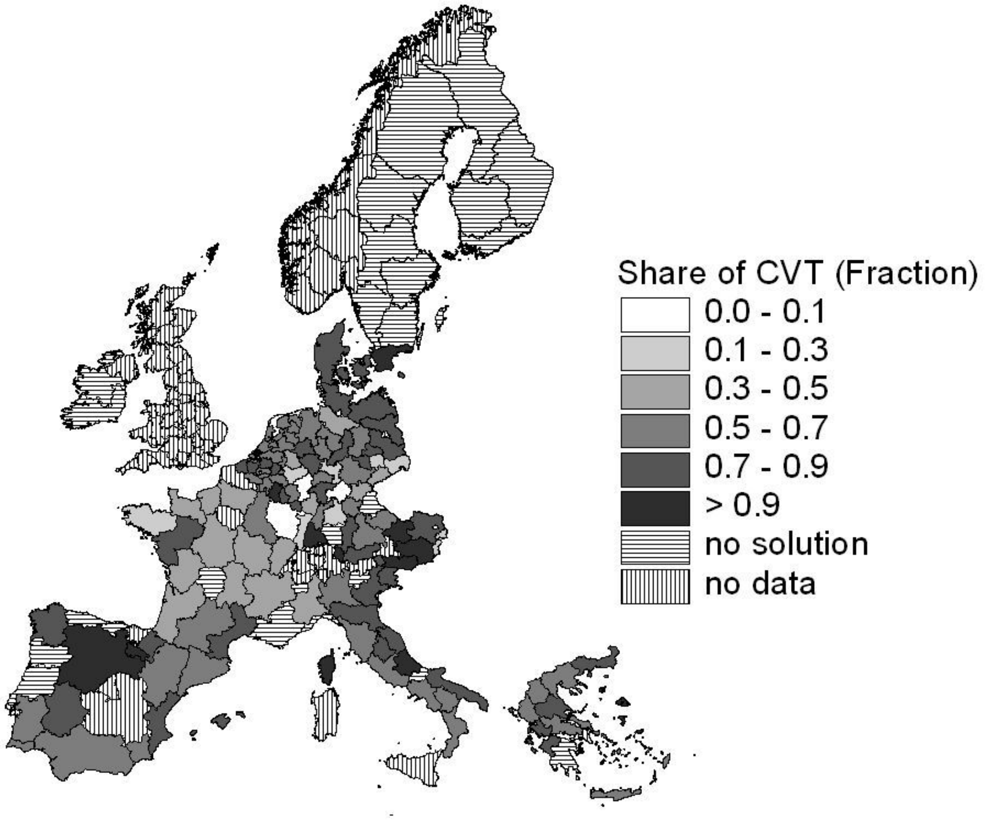


Figure 20: Total Share of Conservation Tillage in Scenario SOC10

In absolute values, however, there is nearly no region where conservational tillage is completely renounced. Although numerous regions decrease the share of conservational tillage, there is only one region where the case of 0.5 t/ha minimum accumulation applies, and only four regions where the case of 1.0 t/ha minimum accumulation that decreases the share of conservational tillage below 10% applies (see Figure 20). In contrast, in the latter case, in several regions nearly all arable land (more than 90%) is rededicated to conservational tillage.

Table 77: Share of Conservational Tillage in Scenario 2, EU-15 Average

Case	Remark	Conservational Tillage
		(Share in %)
Baseline	(equal to 'min00', scenario 1)	55.9
SOC05		61.4
SOC10		61.8

On average for the EU-15, conservational tillage was realised on 55.9% of arable land if we recall the baseline ('min00', scenario 1). Under the current scenario forcing a SOC accumulation of 0.5 t/ha, the share rises to 61.4% and reaches 61.8% if the 1.0 t/ha limit is mandated (see Table 77). The only slight increase from 61.4% to 61.8% hints towards the higher competitiveness of the other measures apart from conservational tillage if a certain level of conservational tillage is exceeded. Here for scenario 2, where several scenario measures are offered to the model simultaneously, this point is reached earlier than in scenario 1 where conservational tillage made sense up to a share of approx. 80% on average level for the EU-15.

Table 78: Straw and its Uses under Scenario 2, EU-15 Average

Case	TOTAL	Market	Feeding	Field	Litter
			(% share) [t/ha]		
REF	100 [6.18]	27.2 [1.68]	1.6 [0.10]	59.6 [3.68]	11.6 [0.72]
SOC05	100 [5.52]	22.1 [1.22]	1.4 [0.08]	63.8 [3.52]	12.7 [0.70]
SOC10	100 [5.54]	17.5 [0.97]	1.3 [0.07]	68.9 [3.82]	12.3 [0.68]

The third measure, *increase of humus input from plant biomass*, mainly reflects in the amount of straw left for field decay. Below-ground biomass from plants is also a source of humus, but is widely untouched by the scenario measures. For the scenario cases, the amounts of straw that are left on field are shown in Table 78, together with the alternative uses of straw. In the reference situation, 3.68 t/ha of straw remain on field on average for the EU-15, 3.52 t/ha in 'SOC05', and 3.82 t/ha in 'SOC10'. Despite these ups and downs, the share continuously increases from 59.6% in the reference, via 63.8% to 68.9%. The increasing relative shares at decreasing absolute values are explained by straw being a product coupled to cereal production. In the scenario cases, however, the production of cereals falls short. The use of straw as litter remains nearly unaffected by the scenario, since litter demand is from animal production where the refining of straw is better than in arable farming. Straw is the only source of litter in the model. In contrast, the quantity of straw that goes into animal feeding decreases since in the model it can easily be substituted by other fodder material. The amount and the shares of straw sold on the market also decrease, although sales quantities stick to a rather high level (based on a sales price of 1.56 - 1.77 EUR/dt).

To summarise the findings all four scenario measures, it seems that each contributes to keeping scenario costs as low as possible. There were only 4.1% (5 regions) in 'SOC05' and 1.8% (2 regions) in 'SOC10' which did not adopt any measure. Measure (4), the combination of the measures (1) - (3), is the most favoured. As can be seen in Table 79 on the average of EU-15 all measures are adopted. The share of non-cereals other than maize or tuber crops ("ONC") is increased in the crop rotation at the expense of cereals. The share of conservational tillage and of straw left for field decay rises. Under 'SOC05' the share of conservation tillage, the share of humus accumulating crops, and the share of straw left for decay on fields is increased. Under 'SOC10' there is nearly no additional adoption of conservational tillage, but still more straw is left for decay on the field and the share of other non-cereals is further expanded. Finally, all the findings support the interpretation that a single most competitive measure does not exist.

Table 79: Combined Adoption of Scenario Measures, EU-15 Average

	Crop Shares				**CVT-**	**Straw for**
Case	**CER**	**MAZ**	**ONC**	**TUB**	**Share**	**Field Decay**
		(%)			(%)	(%)
REF	58.0	11.0	26.0	5.0	55.9*	59.6
SOC05	56.0	11.0	28.0	5.0	61.4	63.8
SOC10	50.0	13.0	32.0	5.0	61.8	68.9
				(change in %-points)		
REF	0.0	0.0	0.0	0.0	0.0	0.0
ΔSOC05**	-2.0	0.0	2.0	0.0	5.5	4.2
ΔSOC10**	-8.0	2.0	6.0	0.0	5.9	9.3

** This share is not from the reference situation, but from min00-scenario 1 (baseline).*
*** Change in comparison to reference situation.*

Aggregated to total **EU-15 level,** the obligation to accumulate at least 0.5 t SOC/ha ('SOC05') entails a carbon accumulation of 24 Mill t of SOC on all arable land. This corresponds to a total mitigation (i.e. including baseline emissions) of 93.2 Mill tCO_2e. If at least 1.0 t/ha of SOC ('SOC10') must be accumulated, the total mitigation reaches 181.3 Mill tCO_2e. At the same time, the scenario costs aggregated for the entire EU-15 amount to 642 Mill € under 'SOC05' and to 2,011 Mill € under

'SOC10'. In other words, the mitigation costs are 6.89 €/tCO$_2$e under 'SOC05' and 11.09 €/tCO$_2$e under 'SOC10'.

However, these mitigation costs arise from the comparison of the gross margins of the scenario cases to the reference situation. In the reference situation, conservational tillage is not an alternative which, as already has been mentioned, contradicts statistics. Comparing thus the scenario costs not to the reference situation but to the baseline, 'min00' of scenario 1 in which conservational tillage is free of choice, the scenario costs would be higher by 7.32 €/ha (the additional gross margin if conservational tillage was free of choice).

4.4.5 Critical Remarks

In interpreting the results of scenario 2, two critical points should be taken into account. First, the results are biased on the EU-15 average level where regions with missing farm level results were excluded. Second, each generalisation of results is difficult since the found inter- and intra-regional reactions to the scenario measures and natural conditions are very different.

Table 80: Exclusion and Inclusion of Regions with "No Solution" in Cases of Scenario 2, EU-15 Average

		SOC05		**SOC10**	
Item	**Unit**	**Excl.**	**Incl.**	**Excl.**	**Incl.**
		(rounded values)		(rounded values)	
accumulation	Mill t SOC	24.0	25.0	48.0	48.0
mitigation	Mill tCO$_2$e	93.2	97.6	181.3	182.5
mitigation cost*	€/tCO$_2$e	6.9	74.7	11.1	65.0
	€/ha	13.4	146.4	41.9	247.0
	Mill €	642.0	7,306.0	2,011.0	11,862.0

** If compared to the reference situation.*

There are 17 regions in which single or all farms did not return a valid solution under the weaker scenario case and 25 regions under the stronger scenario case. The treatment of these regions leaves a notable mark on the average values. So, for example, the total SOC accumulation in the EU-15 which amounts to 24 Mill t if excluded and 25 Mill t of SOC if included (see Table 80). Looking at the mitigation costs, the effect of the exclusion respective inclusion is by far more significant. Under 'SCO05' mitigation costs are 6.89 €/tCO$_2$e but go up to 74.66 €/tCO$_2$e and under 'SOC10' they go up from 11.09 to 65.01 €/tCO$_2$e. The mitigation costs per ton of

CO_2e even go down which can happen as different farms are included into the analysis.

If we generalise from the findings of the scenario, the following can be stated: The presumed popularity of conservational tillage is confirmed since it has expanded over reference levels in more than 30 regions. As to the number of regions that implement the measure, rotational adaptations are even more popular since they are adopted in nearly all regions. On an average level, leaving straw on field as a source of humus is also well-accepted. Correlations between the single measures do exist, although no most appropriate combination of measures has been identified.

An identification of clear tendencies in the correlation of the three scenario measures (conservational tillage, crop rotation, and straw left on field) was not possible. This might partially be due to having neglected a fourth variable of the SOC accumulation in the discussion. This is the HRU[77] specific SOC accumulation rates. Therein, apart from the other three variables, also the prevalent soil (soil type, stoniness, humus content, etc.) is reflected.

The potential impact of this HRU-specificity can be read, for example, in the intensive livestock farm ("IntAnimal") of the Belgium "Brabant Wallon". Despite featuring the highest share of tuber crops, the shares of conservational tillage and of other non-cereals and of straw left for field decay nearly remains unchanged in comparison to the reference situation. This limited reaction can be explained by the relatively high SOC-accumulation of 0.25 t already prevalent in the baseline. A further argument is the general rotation specificity of SOC-accumulation rates. In the exemplary case of Brabant Wallon the SOC-accumulation in the initial rotation is very different from the rotation realised in the scenario. This means that, depending on starting point and site, already a slight change of the crop rotation can translate into the use of a different rotation with different SOC-accumulation as rotations are introduced in discrete steps into the model.

In Brabant Wallon 10%-points of cereals are replaced by non-cereals which is means the farms jumps from the initial rotation 51 ('ROT51') to rotation 43 ('ROT43'). Now, in the cereal marked rotation 'ROT51' SOC is released in case of a no-till tillage scheme (see Table 81). In the less cereal marked rotation 'ROT43', in contrast, SOC

---

[77] Definition of Homogenous Response Unit (HRU) in chapter 3.2.1.

can be accumulated in the extent of up to roughly 4 t/ha. This wide range is at least for the case all straw was left on the field (‘Straw100’ in the table). In the cereal marked rotation the effect of straw left for field decay is only marginal or even negative. In contrast, in the less cereal stressed rotation the difference entailed by straw is as high as 0.592 t (0.740 minus 0.148) under conventional tillage and as high as 3.239 t (4.049 minus 0.810) of SOC. Apart from the example shown, however, the EPIC simulations indicated that cereal marked rotations more often show the tendency to reward straw left for field decay above average with respect to SOC accumulation rates.

Table 81: Example: EPIC SOC-Accumulation Rate, Brabant Wallon

	ROT51*		**ROT43****	
Soil Management	**Straw0**	**Straw100**	**Straw0**	**Straw100**
	(t C/ha)			
conventional	-0.017	-0.083	0.148	0.740
mulch seeding	-0.011	-0.054	0.511	2.557
no-till	-0.006	-0.030	0.810	4.049

**: CER 0.50-0.70, MAZ 0.10-0.30, GRL 0.00-0.10, TUB 0.10-0.30.*
***: CER 0.30-0.50, MAZ 0.10-0.30, GRL 0.10-0.30, TUB 0.10-0.30.*

In summary, the effectiveness and efficiency of the scenario measures is highly variable across regions. For farms in many regions, the mandated accumulation rates of 0.5 t/ha or 1.0 t/ha are unachievable. For other regions, the potential of the adaptation measures remains far behind what was expected, while in other regions only slight changes have already brought the desired result. Other critical remarks related to scenario 1 like the overestimate of the conservational tillage rate or the fact that agricultural prices are not up to date also apply to scenario 2.

4.4.6 Comparison to Scenario 1

The reasoning behind the conception of scenario 2 was twofold: the disappointingly low SOC accumulation under scenario 1, and the assumption that a combination of measures is more competitive to achieving higher accumulation than conservational tillage alone. It is interesting to correlate the accumulation rates to the shares of conservational tillage. It seems that conservational tillage alone is not the most appropriate way to achieve high accumulation, since the higher accumulation of scenario 2 is achieved at lower shares of conservational tillage. In scenario 2 the SOC accumulation is 200 to 400 times above the one in scenario 1 while the share of conservational tillage is only around 60% compared to up to 100% in scenario 1. There is seemingly a better way to stimulate SOC accumulation than solely forcing conservational tillage.

Table 82: Comparison of Scenario 1 and 2, EU-15 Level

Scenario	**Total SOC**	**Change SOC to Reference**		**Change GM to Reference**			**CVT Share**
	(Mill t)	(Mill t)	(kg/ha)	(Mill €)	(€/ha)	(€/t)*	(%)
REF	**-0.89**						
Min40	-0.87	0.02	1	370	6.90	17,825.05	63
Min70	-0.81	0.08	2	294	5.48	3,775.81	75
Min100	0.12	1.01	32	-1,053	-19.60	-1,041.75	100
SOC05	24.00	24.89	500	-642	-13.37	-6.89	61
SOC10	48.00	48.89	1,000	-2,011	-41.86	-11.09	62

**: Per ton of SOC mitigated.*

In Table 82 the total SOC-accumulation rates under both scenarios are opposed to each other. In scenario 1, it was at 1 to 2 kg/ha while in scenario 2 it is between 500 and 1,000 kg/ha (compared to the reference). The total accumulation is maximally around 1 Mill t in scenario 1 compared to 24 Mill t respective 48 Mill t in scenario 2. A second aspect is the change of GM in both scenarios and ultimately CO_2-abatement costs. In scenario 1 the cases ‘min40’ and ‘min70’ still generate scenario gains summing up to 370 respective 294 Mill € for the EU-15. In the case ‘min100’, however, costs of 1,053 Mill € occur. This compares to costs from 642 to 2,011 Mill € in scenario 2.

Generating a unique reference, the change of GM per hectare -19.60 €/ha under ‘min100’ and -41.86 €/ha under ‘SOC10’. Since it is not the objective of this study to identify the cheapest scenario case, but to identify the most competitive scenario case as to SOC mitigation, mitigation costs per ton of SOC mitigated shall be indicated. In scenario 1 the mitigation costs for the strongest case ‘min100’ are 1,041.75 €/t while in scenario 2 they are from 6.89 €/t to 11.09 €/t (also Table 82). This is a difference by the factor 100. In the weaker scenario cases of scenario 1 (‘min40’ and ‘min70’), however, considerable mitigation gains appear. This situation is, however, misleading, since the mitigation gains are due to marginal mitigation quantities and not to extraordinarily high scenario gains. In the case ‘min40’, for example, an overall scenario gain of 370 Mill € in the EU-15 is opposed to a mitigation of only 0.02 Mill t SOC.

Table 83: Mitigation Costs in Scenario 1 and 2, Farm Level, Extreme Regions

				Farm Type**			
Value*	**Scenario**	**Case**	**Region**	**ARA**	**FOR**	**ILS**	**MIX**
					(€/ha rounded)		
MIN	2	SOC05	Aquitaine (France)	-13	-16	-65	-16
		SOC10		-369	-136	-84	-199
	1	min40		7	12	6	9
		min70	Liège (Belgium)	1	12	5	8
		min100		-349	-61	-1	-294
MAX	2	SOC05	Puglia (Italy)	15	16	15	16
		SOC10		14	15	15	15
	1	min40		27	28	27	28
		min70	Itä Suomi (Finland)	27	28	27	28
		min100		18	24	23	19
MEAN	2	SOC05	'Mean' (EU-15)	-16	-9	-21	-15
		SOC10		-41	-28	-39	-31
	1	min40		7	8	8	7
		min70	'Mean' (EU-15)	5	7	7	6
		min100		-35	-3	-9	-21

**: Values of most extreme regions with maximal losses (MIN), largest gains (MAX), and the mean values (MEAN).*
***: ARA arable, FOR forage growing, ILS intensive livestock, MIX mixed farm.*

Apart from the indicated average mitigation costs it is worthwhile to recall the regional results. In both scenarios large intra-regional variability was revealed. There, scenario 2 looks worse on a per hectare basis with higher losses and lower gains in the respective scenario cases (Table 83). But again, the achieved desired impact on SOC accumulation was significant smaller in scenario 1. In both scenarios the arable and the mixed farms are the worst off for the most extreme regions shown in the table. On a mean level, the effects of these tendencies are watered down in both scenarios.

4.5 Scenario 3: Biogas Production

The objective of the scenario "Biogas Production" is to analyse the production potential for biogas in the EU-15. It shall be assessed under the conditions of free competition to other agricultural activities. That is why biogas production is integrated as a further production alternative into EU-EFEM. Major plant characteristics, like fermenter sizes and the combination of substrates, are optimised by the model, i.e. they are integrated into the objective function (see section 3.3.4). In any study region and in any modelled biogas plant, all accruing biogas is utilised in a CHP and the remuneration of outputs is according to the conditions of the German EEG, this includes remuneration in study regions located in other countries. In the scenario the hypothesis is that the conditions of the German EEG will release a significant production potential. An additional hypothesis is that in this economic surrounding the utilisation of waste heat will be a critical driver in biogas production.

The scenario does not mandate any scenario obligations due to the integration mentioned as an alternative production activity. No upper or lower production limits are constrained. In general also the combination of substrates is not constrained. Because the model is restricted to biogas plants run as liquid systems, however, the physical requirements of a pumpable substrate mixture are to be obeyed. This restriction finally forces slurry as base substrate and allows crops only as co-substrates (mono-fermentation of crops is excluded). The scenario of the completely free combination of substrates is further restricted by the constraint of the maintenance of a positive or at least equilibrated humus balance. This condition is from the 2003 reforms of the AGENDA 2000, but is disregarded in one scenario case for its assessment.

Potential scenario measures can be categorised into two crops. The first group comprises the crops that optimise the farmer’s gross margin in biogas production (implementation of biogas production, one out of three possible CHP plants, optimal fermenter volume taking into account substrates volume and available CHP capacity). The second group of scenario measures addresses the maintenance of an equilibrated humus balance. In theory, measures could include the modification of crop rotation, the increase of humus input via straw, and the adoption of conservational tillage. In this scenario, however, the latter is not an option. Its implications on the farm’s gross margin and on the other measures are too large to be separated from the implications of biogas production. Further, biogas production and conservational tillage are both formulated as integer activities in the model (see sections 3.2 and 3.3.4). A simultaneous analysis of the variable for biogas production and conservational tillage overloads EU-EFEM’s integer solver[78] (integer variables exorbitantly increase the iteration process of any solver for such models).

---

[78] COIN-CBC

If constrained to the maintenance of a positive or at least equilibrated humus balance, the SOC-accumulation simulated by EPIC theoretically could be drawn upon. This, however, does not make any sense since conservational tillage, for which EPIC simulations were designed, cannot be considered in the biogas scenario as mentioned. The humus balance is controlled by default values of humus accumulation/consumption from the Cross-Compliance regulation (in its German edition) (compare section 3.2.4) instead of SOC values simulated by EPIC.

The scenario's considered cases are the following:

(1) "BG00+": 0% heat utilisation and positive humus balance,

(2) "BG05+": 50% heat utilisation and positive humus balance,

(3) "BG10+": 100% heat utilisation and positive humus balance, and

(4) "BG05-": 50% heat utilisation without positive humus balance mandated.

The scenario's main achievement is in its flexible integration of biogas production, which does not predefine full biogas plants, but leaves the model major flexibility in the design of the fermenter and the combination of plant substrates. The aspects of profitability of biogas production are integrated into the model (as defined by LFL SACHSEN, 2008, p.11). The aspects a) reliability of production, b) financing concept, and c) down times, are integrated as default values. The aspects d) running and maintenance costs, e) heat utilisation concept, f) substrates, c) costs of substrates, and d) investment costs, are modelled internally and not only as default values. In contrast to the remainder production activities in EU-EFEM, the activity "biogas production" also integrates fixed costs and not only variable costs (the argumentation line is in section 3.3.4). Therefore, in this chapter it is appropriate to use the term "profit" instead of "gross margin."

For the accounting of the energy sources replaced by biogas it is assumed electricity was delivered to the electricity grids and heat was displacing heating oil (on-site or off-site). In EU-EFEM the simulated energy yield for grassland is from 11,200 kWh/ha to 37,504 kWh/ha and from 19,110 kWh/ha to 57,186 kWh/ha for maize.

4.5.1 EU-15-Level: Economic Results

The production potential of biogas can be expressed by the total energy produced (in GWh per year) composed of electricity and heat. The total electricity and heat production are shown in Table 84 for all four scenario cases. The scenario cases reflect different degrees of heat utilisation and the status of the cross-compliance regulation on an equilibrated humus balance. It was hypothesised that the utilization of waste heat was a main driver for biogas production. This is confirmed. In the table, biogas production changes with the degree of waste heat utilization. At 0% thermal energy recovery[79] ('BG00+'), total energy production is lowest with 108,077 GWh (only electricity). At 50% thermal energy recovery ('BG05+'), total energy production more than triples to 359,755 GWh (electricity production doubled to 253,516 GWh). A heat utilisation degree of 100% ('BG10+') does not triple total energy production another time, but it again entails an increase of total energy by 82% (and of electricity by 42%) to 653,756 GWh.

Table 84: Energy Production in Biogas Scenario, EU-15 Level

Energy Type	**BG00+**	**BG05+**	**BG10+**	**BG05-**
		(GWh/a)		
Electric	108,077	253,516	360,336	277,216
Thermal	0	106,239	293,420	117,437
Total	**108,077**	**359,755**	**653,756**	**394,653**

The impact of forcing an at least equilibrated humus balance, i.e. of the cross-compliance regulation, can be read from the comparison of 'BG05+' and 'BG05-', two scenario cases that only discriminate against each other with respect to the regulation on the equilibrated humus balance. Abolishing the obligation to maintain an equilibrated humus balance ('BG05-'), farms are endowed additional flexibility in the composition of crop rotations. The widened scope of crop rotations also affects biogas production, which is increased by 35 thd. GWh in total energy (394,653 GWh compared to 359,755 GWh).

This considerable production of biogas binds resources lying at hand. The substrates for biogas production in theory can be from manure and/or from crops (grassland and arable land). Manure solely refers to transportable manure, i.e. liquid and solid manure from animal confinements, but not to manure from grazing animals.

---

[79] It is the available net thermal energy. The share necessary for fermenter heating has already been deducted.

As can be seen in Table 85, in the scenario cases, between 108 and 371 Mill t of manure are digested in biogas plants. The amounts thereby increase with the produced electricity (respective biogas). The utilization of crops as co-substrates behaves in a similar fashion. From the main co-substrate, maize, 194 to 557 Mill t are fed to digesters. Grass contributes between 55 and 202 Mill t. The cultivation of these crops and other crops utilized as co-substrates binds between 6 and 21 Mill ha. Half is maize and half is grassland area.

Table 85: Resource Demand of Biogas Production, Absolute, EU-15 Level

Category	BG00+	BG05+	BG10+	BG05-
		(Mill t, wet weight)		
manure for biogas*	108.3	270.5	370.8	271.8
- liquid	101.2	247.1	332.7	248.1
- solid	7.1	23.4	38.1	23.7
Maize	193.8	412.7	556.8	476.1
Grass	55.4	132.9	202.0	131.4
		(Mill ha)		
land for biogas	5.7	15.0	20.6	18.3
- arable	2.9	7.6	10.9	11.1
- grassland	2.8	7.4	9.7	7.2

** Only transportable manure.*

Special attention is owed to the comparison of applied substrates in scenario cases ‘BG05+’ and ‘BG05-‘, which expresses the effect of the at least equilibrated humus balance. Relieving the at least equilibrated humus balance, the amount of manure and grassland remain nearly unaffected, but the utilization of maize is increased clearly. Maize is utilised at 63.4 Mill t more in ‘BG05-‘ than in ‘BG05+’ (412.7 - 131.4). This reaction speaks for the improved competitiveness of arable land in case of a relieved humus balance.

The shares of manure and the share of crops that are utilized as substrates in biogas production are presented in Table 86. In general, the scenario cases bind significant shares of manure and of crops. Depending on the scenario case, between 19.2 and 60.2% of the total (transportable) manure is fed into the digesters and between 6.1 and 22.3% of the total land is for the production of crop substrates. In each of the analysed scenario cases, the degree of utilisation of grassland exceeds the degree of arable land. In grassland the share is between 8.1 and 28.7%, and in arable land it is from 4.9 to 18.9%. In order to tap the highest biogas production potential, over 22% of total agricultural land and over 60% of manure are for biogas plants.

Table 86: Resource Demand of Biogas Production, Relative, EU-15 Level

Category	**BG00+**	**BG05+**	**BG10+**	**BG05-**
		(% of total)		
Land for biogas*	6.1	16.2	22.3	19.8
- grassland	8.1	21.7	28.7	21.3
- arable	4.9	13.0	18.5	18.9
Manure for biogas**	19.2	45.3	60.2	46.4

** Percent of total land in category. ** Percent of total manure.*

Especially in the case of manure, the range between maximal share found in the analysis, and along its range among the scenario cases is tremendous. The latter is from 19.2% via 45.3% to 60.2% (‘BG00+’, ‘BG05+’, ‘BG10+’). This is equal to an increase by 136% for the first step and by another 33% for the second one. The increase in the absolute amounts of manure (Table 85) even tops these rates: 150% for the first step and 37% for the second one. Since the absolute amounts of manure going to biogas plants increase more strongly than the share as per total available manure, it means that the total available manure increased. This is confirmed in Table 87. As the unique source of manure, also the animal numbers are displayed, which logically also increased.

Table 87: Interaction Biogas and Livestock Production, EU-15 Level

Category	**Unit**	**BG00+**	**BG05+**	**BG10+**	**BG05-**
total manure*	(Mill t)	564.0	596.6	615.8	585.2
increase in animal numbers**	(1000 LU)	91.8	193.4	193.4	120.7

** Total accruing manure, not only that which is directed to biogas plants (wet weight). ** In relation to reference situation.*

The reasons behind the positive correlation found between biogas and livestock production cannot be clearly fixed, since EU-EFEM as mixed-integer programming model does not provide a dual solution. Only from the dual solution could the shadow prices be taken as indicator for the valuation of the resources utilization[80]. Only presumptions can be made instead. The increase of livestock production could originate from an increased profitability due to the monetarisation of manure in the

---

[80] If a LP problem is interpreted as “resource allocation problem”, then the dual problem can be interpreted as “resource valuation problem”. The shadow price is the opportunity cost of the exploited resources.

energy recovery by the biogas plant. It might also be that the potential monetarisation of manure and the utilisation of grassland as substrate function in the same direction, i.e. through the additional units of manure from livestock production, grassland production can be intensified and becomes more profitable. Also, technical limitations of biogas production, seen in the pumpability of the substrate mixture, could be the reason. Any additional unit of liquid manure allows for an additional unit of plant substrates in the mixture. This is a relation that is important at a certain point. However, this argumentation can be dropped since in ‘BG05-‘ animal numbers are larger than in ‘BG05+’, although the amount of manure utilised as substrate remained unaffected.

Whatever reason might really stand behind the positive relation between livestock and biogas production, the argumentation is limited to a linear (mixed-integer) model like EU-EFEM. If the model balanced markets via supply and demand functions (like (general) equilibrium models do), most probably such a tremendous increase in livestock production would not be simulated. Rather it can be assumed that biogas production through increased demand for crops and animals would increase crop and animal prices. Remember that the degree of utilisation of arable land as source of biogas substrates reached as much as 22.3% of total arable land, and the utilisation of grassland reached 28.7% at maximally found biogas production rates (see Table 86). This is a vast displacement effect.

4.5.2 Aggregated Regions: Economic and Environmental Results

It has previously been shown that farms implement biogas production in the EU-15. Yet the economic implications have not been described. In contrast to the other scenarios, the biogas scenario is free of any scenario costs, since it is implemented freely and as such will be implemented only in cases where profits can be generated through the biogas plants.

On level of the EU-15, the range of additional profits that is generated in the scenario is from 1.6 Bill € to 9.2 Bill € depending on the scenario case as illustrated in Table 88. Logically, the highest gain is realised if all thermal energy is monetarised, whilst the lowest is achieved if no thermal energy can be used. Enforcing an at least equilibrated humus balance, the gains are reduced by roughly 0.9 Bill €. This can be read from comparing ‘BG05-’ to ‘BG05+’ (5,148.8 Mill minus 4,291.4 Mill).

Table 88: Economic Impact of Biogas Scenario, EU-15 Level

	BG00+	BG05+	BG10+	BG05-
	(in Mill €)			
Additional Profit	1,561.6	4,291.4	9,228.4	5,148.8

While the motivation of the farmer for a biogas plant is in the additional gross margin, the motivation by policy for subsidising biogas is firstly in the promotion of a renewable energy generation. Renewable energy generation gives independence from energy imports and it is a means to reduce GHG emissions. The emission reduction achieved is calculated as the sum of the three major components: 1) renewable energy replaces fossil fuel combustion (fuel switch), 2) avoids methane through improved manure management, and 3) increases emissions in the production and application of synthetic fertilisers for the cultivation of biogas substrates.

In the model, the energy from biogas is recovered in the form of electric and thermal energy in a combined heat and power plant. It is further assumed that that electricity would replace electricity from the electricity grid and thermal energy would replace light heating oil. In most EU member states grid electricity is produced from various sources, among them fossil sources, nuclear power, and renewable sources. The German energy mixture for power generation entailed an emission of 761 tCO_2e/GWh beginning of the new millennium (compare section 2.3.3). In light of the lack of national grid emission factors, the German factor is used instead. Heating oil replaced by the CHPs' thermal energy features an emission factor of 3.079 tCO_2e/t of oil (IPCC, 2006c). Other additional emissions in opposition to emission reduction affected by biogas production are "improved manure management" and "fertiliser production and application". These sources are accounted for as described in section 3.3.5. The application of fertilisers is accounted for with IPCC "Tier 1" (the application of manure as emission source is disregarded, since the amounts of manure remain nearly unchanged across the scenario cases and since the effect of the additional manure could also be attributed to increased livestock production instead of to increased biogas production).

The total emission reduction achieved by biogas production is from 46.7 Mill t ('BG00+') to 263.1 Mill tCO_2e ('BG10+') (see Table 89). The fuel switch contributes the largest emission reduction (69.3 to 322.6 Mill tCO_2e). It is partially compensated for by increased emissions due to (additional) fertiliser production and application (23.7 to 63.7 Mill tCO_2e). Against the total emission reduction, the emission reduction achieved by improved manure management is negligible (1.1 to 4.2 Mill tCO_2e).

Table 89: Emission Reduction in Biogas Scenario, EU-15 Level

Item	**BG00+**	**BG05+**	**BG10+**	**BG05-**
		(Mill t of CO_2-equivalents)		
Total	**46.7**	**147.5**	**263.1**	**160.4**
- fuel switch	69.3	192.9	322.6	212.2
- manure management	1.1	2.9	4.2	2.2
- fertiliser*	-23.7	-48.3	-63.7	-54.0

** Includes emissions from fertiliser production and IPCC direct emissions from application.*

With the previously presented scenario gains and the scenario's emission reductions in CO_2-equivalents, all values are at hand to calculate CO_2-mitigation costs. Since in the biogas scenario only scenario gains are entailed while at the same time emissions are reduced, the mitigation costs will be negative (corresponding to "mitigation gains"). However, the validity of this statement is restricted to farm level results. On a macro-economic level, the subsidies paid by the state to biogas producers have to be taken into account (here, in form of renewable energy bonuses through the German EEG considered). The subsidy is assumed to equal the difference between the remuneration of biogas electricity minus the reference price of electricity in Germany. The reference price of 4.0 ct/kWh (ZYBELL and WAGNER, 2006; BODE and GROSCURTH, 2006) reflects a rough estimate of electricity production costs among different plant types which vary from 1.5 ct/kWh in nuclear power plants or large amortised hydropower plants to 10.0 ct/kWh for peak load production. The so calculated subsidy is then added to the farm level mitigation costs in order to obtain the macro-level mitigation costs.

On a farm level, the mitigation costs are between -35 and -29 €/tCO_2e in the different scenario cases (Table 90). This means that per tCO_2e by which emissions are reduced, a profit between 29 and 35 € is realised. At the same time, the paid public subsidy adds up from 30 to 63 €/tCO_2e in the same scenario cases. Summarizing both parameters the macro-level mitigation costs are calculated. The macro-level mitigation costs, i.e. including the public subsidy, range from -5 €/tCO_2e to +29 €/tCO_2e. Negative mitigation costs of up to -5 € are only realised in 'BG10+', which means if 100% of thermal energy are used. At the same time the subsidy if referred to tCO_2e decreases from 63 € to 30 € from in these scenario cases, i.e. 'BG00+' to 'BG10+'.

Table 90: Emission Reduction Costs in Biogas Production on EU-15 Level

Row	Item	BG00+	BG05+	BG10+	BG05-
			(€/t of CO_2-equivalent)		
1	farms: farm level	-33.45	-29.08	-35.08	-32.11
2	state: subsidies	62.68	37.07	29.98	38.21
3	**public: macro level (1 + 2)**	**29.24**	**7.99**	**-5.10**	**6.10**

That the obligation to maintain an at least equilibrated humus balance increases public mitigation costs from 6.10 to 7.99 €/tCO_2e can be read from comparing scenario cases 'BG05+' and 'BG05-'. This calculation disregards the carbon mitigation in form of SOC contained in the humus fraction. Taking this effect into account, then the cost difference is watered, but only insignificantly. In the case of a forced equilibrated humus balance the SOC mitigation is 1.6 Mill t higher, equal to 2.1 Mill tCO_2e. The mitigation costs change from 7.99 to 8.06 €/tCO_2e for 'BG05+' and from 6.10 to 6.24 €/tCO_2e for 'BG05-'. The enforcement of an at least equilibrated humus balance has only very limited effect on climate, at least if setting the Cross-Compliance values for humus dynamics applied here.

The results of the biogas scenario aggregated to NUTS-I-level are shown in Table 91. The table gives the values for the exemplary case in which 50% of waste heat are utilised. Through the aggregation to NUTS-I-level some information logically gets lost. What can be nicely seen is the area use for the cultivation of biogas substrates. Especially grassland is intensively utilised in some French, German, Spanish and one Italian region with shares of close to 80% of regionally available grassland. In terms of emissions, the scenario emissions, due to additional application and production of synthetic fertiliser, are only marginal compared to the emission mitigation attributable to the fossil fuel switch in heat and electricity production. Farm level mitigation costs (disregarding subsidies), if referred to the two shown emission sources, are in a range from -160.65 to 16.91 € per tCO_2e.

Table 91: Results Biogas Scenario, if 50% Heat Utilization, NUTS-I-Level

	Area Use**		**Emissions**		**Costs**
NUTS-I	**ARA***	**GRAS***	**FSW***	**SYN***	**MITI***
	(% of area in region)		(Mill tCO_2e)		(€/tCO_2e)
be2	11.8	8.3	-1.5	0.2	-9.05
be3	5.2	1.7	-0.4	0.1	-23.19
dk0	38.0	34.8	-14.0	4.3	-25.96
fr2	24.2	65.8	-39.0	6.7	-32.21
fr4	42.5	43.6	-10.1	1.9	-46.99
fr5	53.4	52.9	-45.5	13.1	-25.34
fr6	32.9	46.9	-21.0	3.2	-6.70
fr7	17.0	6.6	-4.0	0.7	-21.43
de1	17.0	11.0	-2.6	0.6	-43.71
de2	14.6	8.4	-5.8	1.0	-18.71
de4	17.5	38.6	-2.1	0.8	-102.54
de7	26.2	60.1	-3.0	0.4	-25.49
de8	28.6	49.2	-4.2	1.4	-80.80
de9	12.2	43.0	-6.0	0.3	-18.69
dea	8.3	19.5	-2.0	0.3	-17.79
deb	9.0	2.4	-0.6	0.1	-22.88
dec	61.5	71.2	-0.6	0.1	-37.85
ded	18.4	19.0	-2.2	0.8	-116.08
dee	18.0	39.6	-2.3	1.4	-160.65
def	33.6	77.4	-4.5	0.3	-12.42
deg	13.3	29.8	-1.4	0.4	-88.43
it2	0.6	0.1	-0.1	0.0	-14.39
it4	17.4	68.1	-5.2	0.6	-7.42
it5	1.2	4.2	-0.4	0.1	-14.05
lu0	38.8	51.6	-0.9	0.1	-4.77
es2	10.9	46.3	-3.0	7.9	16.91
es5	16.6	74.4	-3.2	0.4	-26.27
se0	19.6	33.0	-7.6	1.2	-36.66

**ARA: Arable land, GRAS: Grassland, FSW: Fuel Switch, SYN: Synthetic fertilizer, MITI: Mitigation Costs; **Area Use for Cultivation of Biogas Substrates*

4.5.3 Regional Results

According to the EU-EFEM simulations, biogas production is an important income source for farms in the EU-15. Looking, however, at the distribution of biogas production among regions, then a different picture is painted. In case 0% of thermal energy is utilised (‘BG00+’), for example, biogas production does not takes place in Austria, Denmark, Finland, Greece, Ireland, Italy, Luxembourg, and Portugal. The entire production is concentrated in the other member states. In case 50% of thermal energy is utilised (‘BG05+’), still a number of countries refrain from biogas production like can be retraced in Figure 21. There the regional shares in total European biogas production are shown (energy shares). It is still in Austria, Finland, Greece, Ireland, and Portugal that no biogas is produced. The majority of biogas production is in Danish, French, and German regions where the largest single producer regions achieve a share of up to 10.0% (Pays de la Loire, North Western France). The regions represented in the group '2.58 – 10.00' (percent of total kWh) alone account for above 60% of total biogas production (energy share).

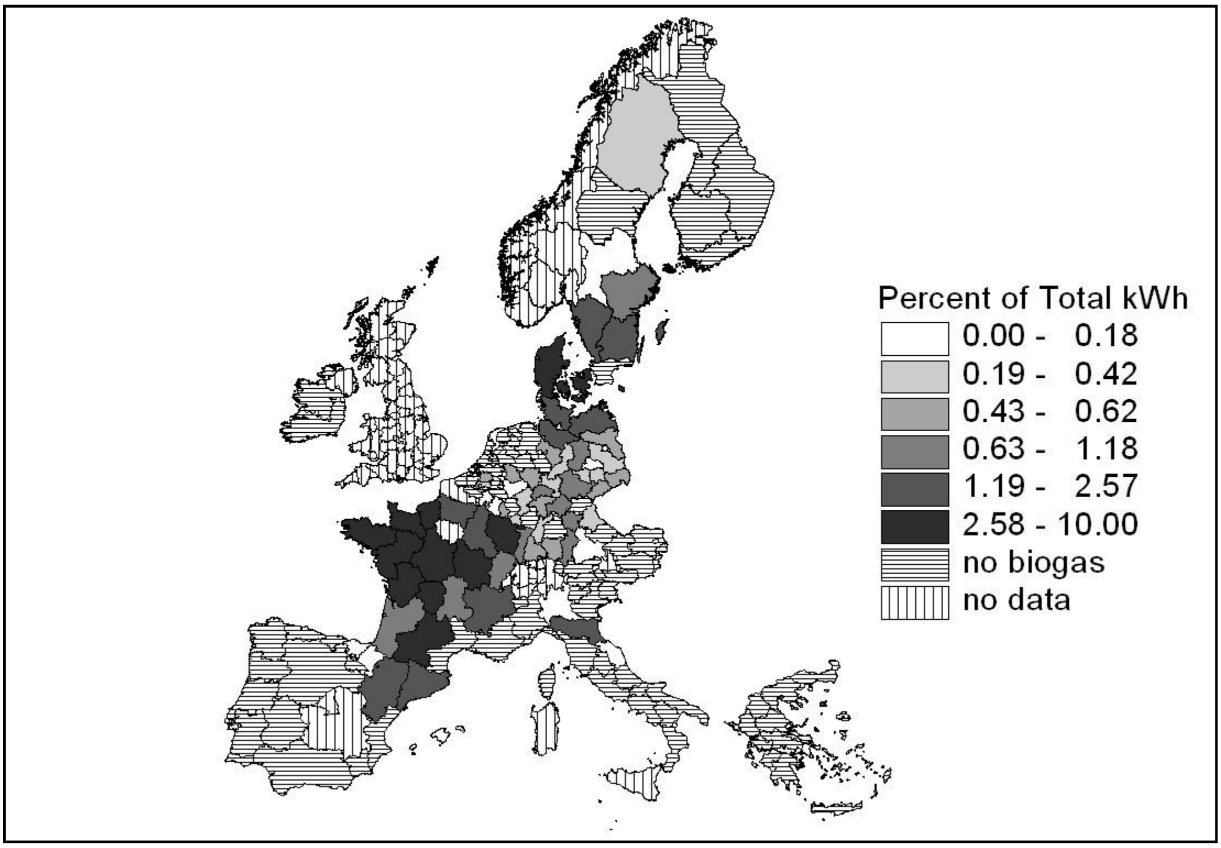


Figure 21: Regional Shares in Total EU-15 Electricity Production, if 50% Thermal Energy is utilised

For the same scenario case ('BG05+'), the share of arable land that is rededicated to the production of biogas substrates is shown in Figure 22. The range is wide and is from 0% to over 60%. The share of rededication surpasses 50% in seven regions and 60% in two regions (Saarland, Germany and Pays de la Loire, France). At the same time it stays below 5% only in five regions (Oberbayern, Navarra, Lombardia, Marche, and Norran Mellansverige).

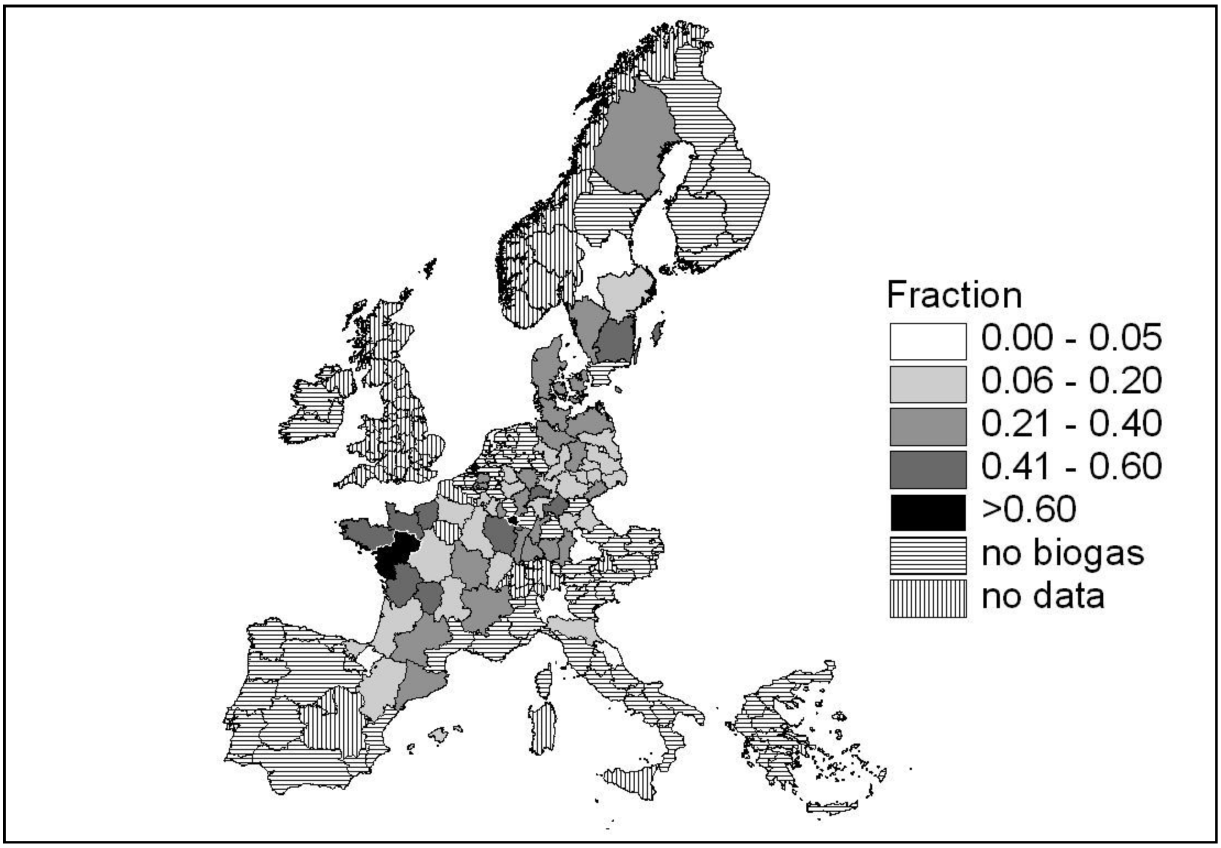


Figure 22: Regional Fractions of Arable Land Dedicated to Substrate Production, if 50% Thermal Energy is utilised

Staying with the same scenario case (‘BG05+’), the share of grassland rededicated to biogas production is from 0 to 80% (Figure 23). Although not readable from the figure, there is only one region that completely fails to use grassland as source. The share of rededication stays below 5% in eight regions. In the other regions, considerable shares are rededicated. In 26 regions the share is in excess of 50%. In three regions it is above 80% (Lüneburg, Basse-Normandie, and Alsace). With respect to weight fraction in the substrate mixture, crops from grassland and arable land had approximately the same importance on a general level (compare Table 85).

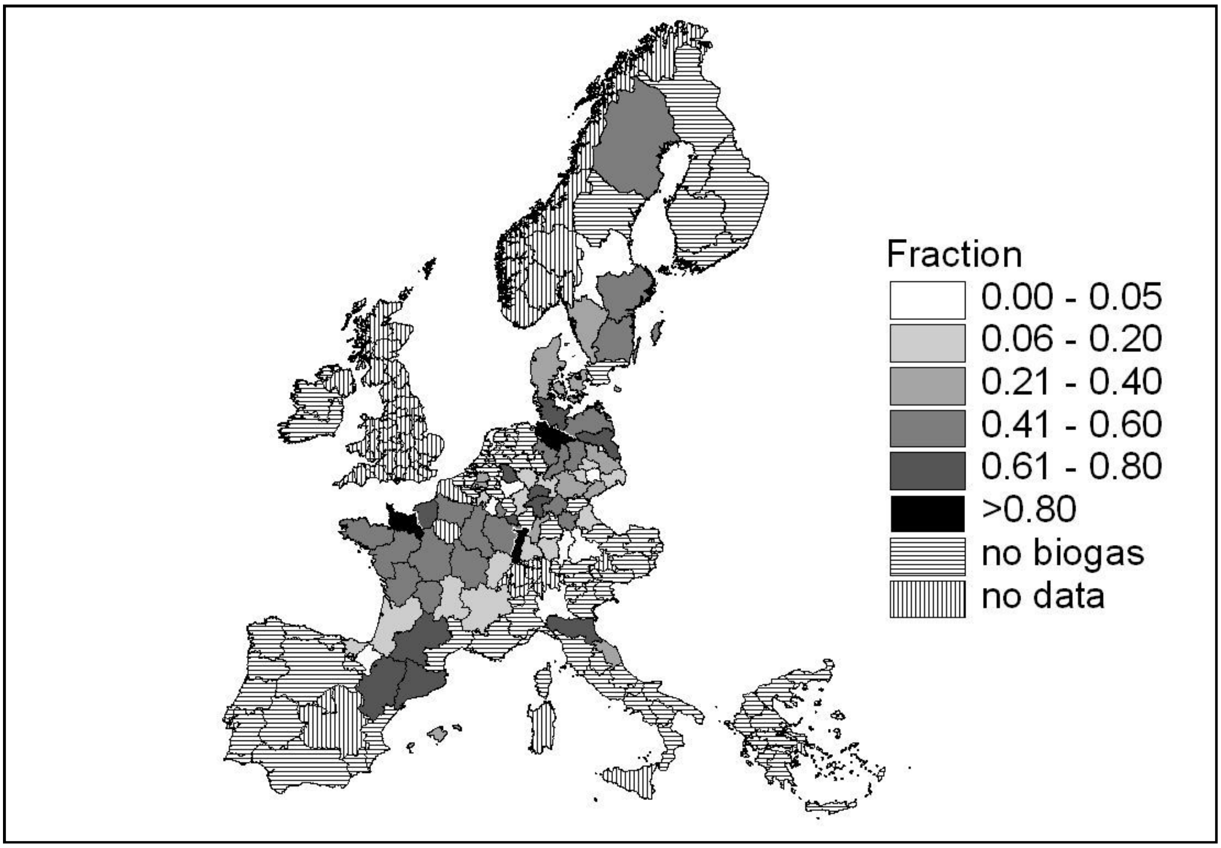


Figure 23: Fraction of Grassland Dedicated to Substrate Production if 50% Thermal Energy is utilised

The third source of substrates is manure. This category combines manure from different animal types and in different aggregate states (liquid or solid). Again for the scenario case ‘BG05+’, the relation between manure and plant substrates if compared on a wet weight basis is illustrated (Figure 24). In Southern France and in Spain the shares are the lowest. In the Spanish Aragón, manure makes up only 10% of the weight of plant substrates (or 9% of the total mixture). In the Spanish and French regions the relative importance of manure is lower than in Germany or other countries. In six out of the 66 biogas producing regions in ‘BG05+’, the share of manure is larger than the share of plant substrates (or above 50% of the total mixture), i.e. in the above figure the fraction is greater than 1.00. The composition of the manure, on an average basis, is 90% liquid and 10% solid manure.

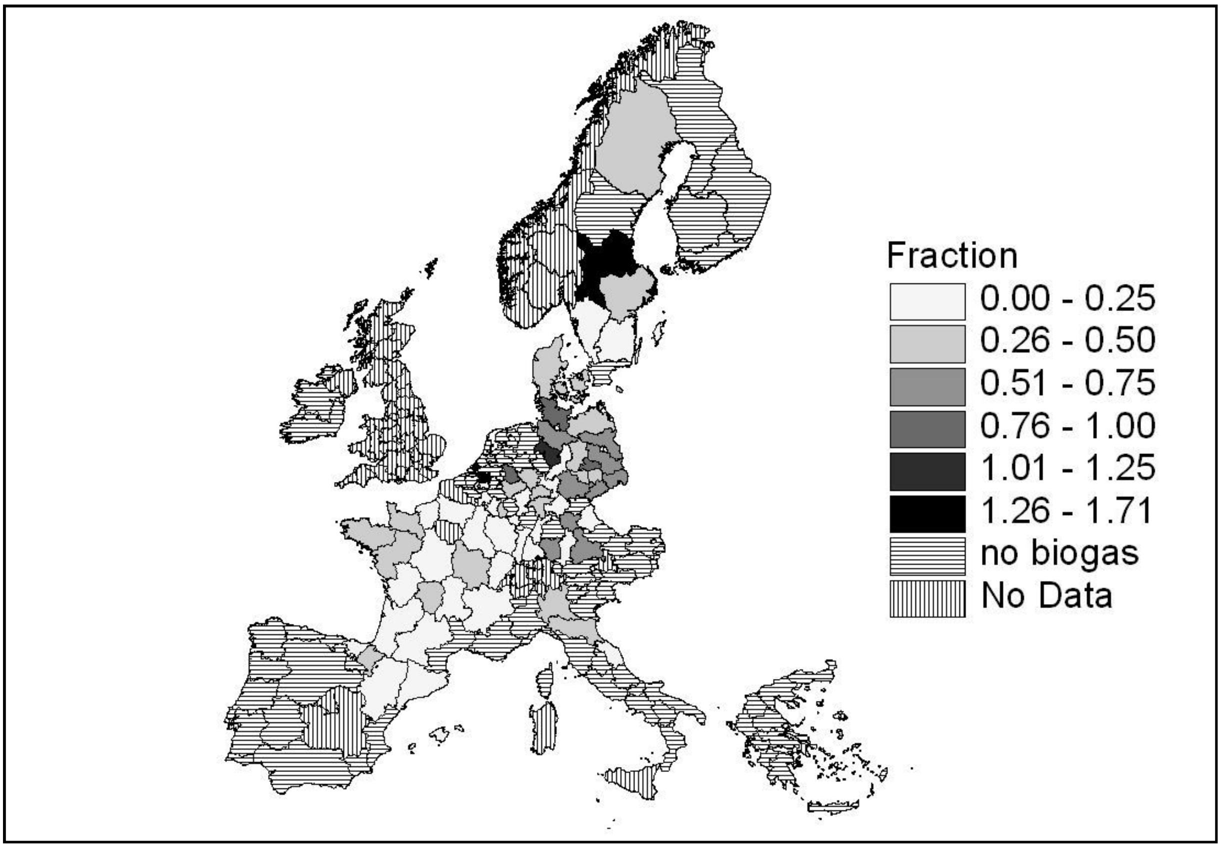


Figure 24: Relation Manure to Plant Substrates if 50% Thermal Energy is utilised (Wet Weight Basis)

On the farm level the picture even becomes more diverse than on the regional level since the farm types have different production factors and factor costs. This shall be mentioned for the adaptability of the farm types to deal with the obligation for an at least equilibrated humus balance. In the first place, it distinguishes arable farms from the other farm types. Relieving this constraint makes them jump into biogas production at a rate that is above average. Since arable farms usually feature low grassland and livestock capacities the availability of other substrates than maize is limited. However, maize is a rather large humus consumer according to the applied default humus values from the Cross-Compliance regulation. The cross-compliance finally impedes larger shares of arable land being brought into the biogas production cycle which might precisely be the desired effect.

4.5.4 Critical Remarks

Firstly, it will be validated if the extent of biogas production simulated by the model reflects reality. Compared to the statistical values, the model overestimates biogas production. Because of the lack of European statistics, however, a comparison is only possible for Germany. For this country an electricity output of 30,816 GWh/a was simulated in the scenario case with the lowest generation ('BG00+'). Assuming a critical minimum runtime for CHP units indicated by producers with 8,300 h/a, this production corresponds to an installed capacity of 3,700 MW(el). According to a German biogas association (FNR, 2007), Germany reached an installed capacity of only around 1,300 MW(el) in 2007, whereof around 85% are attributable to agriculture. In another source the German biogas association indicates the energy potential from biogas in Germany at 354 PJ/a equal to 34,300 GWh/a at 35% electrical efficiency (FNR, 2008). This is thus in line with the potential simulated here. Considering, that biogas production has shown a strong upward trend during the last few years, this might explain the smaller really installed capacity of 1,300 MW(el). In 2005, for example, the installed capacity was only half that of 2007, although similar or even better production conditions were in place (FNR, 2007).

4.5.5 Comparison to Scenarios 1 and 2

For the entire EU-15, the simulated biogas production entails an emission reduction by 46.7 ('BG00+'), 147.5 ('BG05+'), 263.1 ('BG10+'), and 160.4 Mill tCO_2e ('BG05-'). Compared to scenarios 1 and 2, this reduction is in centre-field, but achieved by a limited number of regions, namely the 66 biogas producing regions. In scenario 1 ("*Minimum shares of conservational tillage*") the emission reduction achieved was only 3.7 Mill tCO_2e, even under the most effective scenario case, which, in comparison, is negligible. In scenario 2 ("*Minimum SOC-accumulation rate*"), comparable rates of emission reduction were achieved. There the more effective of the two scenario cases ('SOC10') entailed a reduction of 181.2 Mill tCO_2e.

In turn, the biogas scenario is the only scenario in which public expenditures (subsidised feed-in tariffs) are considered. If this aspect were considered in the other scenarios, scenario 1 and scenario 2 might perform better than the biogas scenario with respect to mitigation costs. On the macro-economic level, the biogas scenario entailed mitigation costs of -5.10 €/tCO_2e if 100% of thermal energy is used and costs of 29.24 €/tCO_2e if 0% of thermal energy is used. In scenario 2 the mitigation costs are from 6.89 €/tCO_2e to 11.09 €/tCO_2e. Compared to scenario 2 mitigation costs are lower in the biogas scenario if 100% of thermal energy can be used. In all other biogas cases mitigation costs are about in the same range. Further, the before statement only applies if utilised thermal energy replaces heating oil.

Scenarios 1 and 2 are mutually exclusive. This is not the case for the biogas scenario, which could be combined with scenario 1 or scenario 2. However, in scenarios 1 and 2 farmers implement conservational tillage widely. In scenario 2 farmers additionally rely on the measure modification of crop rotation towards other non-cereals. The mentioned measures do not fit well with the major crop being maize, which is the case in the biogas scenario. Maize is relatively sensitive to conservational tillage and its share is reduced in the crop rotation under scenario 2.

5 Discussion and Conclusions

This study analyses the potential double function of agriculture in climate change mitigation policies, manifesting in the emissions entailed by agricultural production on one hand, and in the sequestration of carbon dioxide from the atmosphere making the attribution of sink function to agriculture possible on the other hand. For the economical and ecological assessment of this source and sink function a Mixed Integer Programming (MIP)-model was developed and applied. This model maximizes the total gross margin of representative farms under a set of constraints. In this context, for the study region of the EU-15, the determination of gross margins of agricultural production activities represented the study's first major challenge. Estimates of gross margin or its constituents, production costs and revenues, were not available on the high regional resolution sought by this study, which is focused on the NUTS-II-regions (which is usually above provincial level). Since there is a lack of data even for conventional production activities, it is no surprise that information on new activities like bio-energy production or alternative tillage management is really difficult to obtain. A second major challenge is in the analysis of agriculture's sink function. Soil carbon sequestration as the main potential sink was analysed in this study by a new approach aimed at improving the expressiveness of Soil Organic Carbon (SOC)-accumulation in an economic modelling environment like in the model applied in this study. The new approach integrates bio-physical simulation data instead of the usually applied default values. While the default values, e.g. from the Intergovernmental Panel on Climate Change (IPCC), are often on a supra-national level, the biophysical values are site-specific on a 1×1 kilometre grid, thus elevating the level of detail into another sphere.

The challenges mentioned above might already have indicated the focus of the study, which was on methodological issues. Nevertheless, the applied model was tested in a number of scenario runs on SOC-accumulation and on biogas production. In the following seven pages the analysed methodological issues will be summarised and discussed. Following this, selected scenario results will be presented.

5.1.1.1 Methodological Issues

With respect to methodological issues the three major challenges are summarised in the following: 1) estimating regionally diversified gross margins leading to the analysis of production costs, 2) integrating site-specific SOC-values from a biophysical model, and 3) simulating biogas production in a way that leaves maximal production flexibility to simulated farms while integrating fixed costs. Other methodological issues, like the integration of the policy element of the 2003 reforms of the AGENDA 2000, also required a special solution, but will not be mentioned again[81].

The first challenge, delivery of regionally diversified gross margins, manifests in the problem of estimating regionally diversified variable production costs. After variable production cost the second component of the gross margin is revenue. Revenue can be calculated rather easily and accurately. Revenues show limited interregional variation and can be extracted from European statistics. Variable production costs were estimated by means of a new approach based on the combination of engineering cost data with accountancy data. The new approach had to be limited to the plant production branch. This is due to the lower product uniformity in animal production, which would be further aggravated by the joining of engineering cost data. Unfortunately, data against which to validate the obtained estimates is rare (e.g. FADN standard gross margins), so their quality cannot be assessed against hard criteria. The cost estimates not only form the fundament of this study, but will probably also be of use to many other studies/ models.

The second challenge, the integration of biophysical SOC-values into the economic model applied here, also has the potential to spread beyond the borders of this study to wherever the application of site-unspecific default factors has been popular. Biophysical models can simulate site-specific conditions like weather, soil, management, and crop rotation. SCHÄFER (2006) took a first step forward in this direction when he also coupled a micro-economic farm-level model with the biophysical DNDC-model. In this arrangement the data flow was merely one way, from the farm level to the biophysical model and not vice versa, and a modification of the model's structure was spared. Here, in contrast, the data flow is bidirectional and a structural modification of the original model was necessary.

The third challenge is a more flexible integration of biogas production. Usually in Linear Programming (LP)-models, maximizing gross margins and not profit fixed costs are neglected. In order to constrain the production level of new production activities featuring relatively high fixed costs and relatively low variable costs, the

---

[81] Methodological issues are described and discussed in chapter 3.

fixed costs of this activity are forced into the model via a binary variable (compare TRIEBE, 2007 or SCHÄFER, 2006). In this context it is necessary to predefine fixed costs. The challenge faced here consists in finding a way that allows a more flexible integration of biogas production meaning not having to predefine some few biogas plants. Since binary variables eat up large amounts of solver capacity, simulating a large number of biogas plants is not a feasible solution. Instead of providing the model with a large number of predefined biogas plants, maximal flexibility was sought by minimizing the fixed part of predefined biogas plants.

5.1.1.1.1 Methodological Issue: Estimate of Plant Production Costs

The new approach could be referred to as “knowledge based approach combining specific advantages of engineering cost data with those of accounting data”. Engineering cost data are formulated per activity (e.g. ploughing, seeding) and standard activities are formulated per crop. The applied accountancy data, in contrast, feature actuality and farm specificity. Fortunately, the farms, although made anonymous, are attributed a region code and thus can be fitted into the regional level of the model of the study. Neither engineering cost nor accountancy data could be applied alone, as they do not deliver the same service. The first is only representative for German farms, and other national sources of engineering costs data do not exist (KTBL database). The second, although a European database, does not contain costs on a crop level (FADN database), but only on the level of cost items, e.g. “machinery”.

The way in which both sources were combined was not uniform across all cost items separated by FADN. Some of them required a special treatment. The standard procedure, in its simplest form, can be described as follows: for each FADN cost item, costs are redistributed to the crops cultivated by a *farm X* according to their (weighted) cost share in the overall crop mix of *farm X* according to the engineering cost approach. In doing so, the advantages of both data sources can be joined. The German engineering cost data was “internationalised” by merging in national fuel and labour prices.

The FADN costs items are “factor costs”, “maintenance of machinery”, “fuel”, “contract work”, “wages”, “interest paid”, and “contract work”. A special treatment was applied to “factor costs” and to “interest paid”: a) to seeds as part of “factor costs”, because the engineering cost approach is not applicable. The major determinant of seed costs, which is the degree of self reproduction of crops, is unknown, b) to fertilizer as part of “factor costs”, because a model endogenous variable already simulates crop specific fertilizer need and links costs directly to modelling results, c) to electricity as part of “factor costs”, because in the accountancy data there is no division between electricity for plant and animal production and thus the bias would be too large, d) to interest paid, because interest can be added easily as a share of the total production costs; and e) to “contract work”, because its range is too wide to be averaged with the engineering cost data.

Theoretically all production activities could be outsourced and contracted from service providers. This creates the situation that an average value from engineering costs data is too vague. In combination with the large share of contract work costs in overall production costs, a different procedure was adopted. To reduce the number of potential production activities, two core assumptions were made: 1) contract work occurs in activities with extraordinary high fixed costs and 2) contract work occurs mainly during peaks of labour demand where opportunity costs are highest. Both assumptions fall together for harvesting activities. Based on this, a decision-tree-like routine (based on engineering costs of harvesting activities) was formulated for crop groups, where the groups consisted of different combinations of cultivated crops. At the end, again contract work costs indicated in the accountancy data were redistributed to single crops.

The obtained estimates show a wide range. Because of the reasons mentioned above, they exclude fertilizer costs. For example, the range of estimated costs is from 98 to 740 €/ha in winter wheat and from 560 to 1,112 €/ha in sugar beet. However, the range of production conditions, production intensities, and sales prices in the EU-15 is also wide which makes vary gross margins still wider. For the above mentioned crops, for example, it is from -308 to +497 €/ha in winter wheat and from +492 €/ha to +2,317 €/ha in sugar beet. Validation was not possible due to the lack of empirical data for the EU-15, at least on a similar disaggregated regional level. Only for Germany was validation possible, since there the applied engineering cost data exist. In this German database the range of costs (depending on farm structural factors like field sizes) is large enough to explain the range of obtained estimates.

Production costs were also estimated for the alternative tillage management of conservational tillage. The applied FADN accountancy data does not make any difference between conventional and conservational tillage. This is why the approach cited above could not deliver estimates for crops under conventional and conservational tillage separately. Currently, conservational tillage measures are only sparsely spread in the EU-15. So, the bias from assuming conventional tillage as standard tillage management was held to be acceptable. For conservational tillage production, costs were estimated based on the obtained estimates for conventionally tilled crops, summing up the cost difference between both tillage managements according to the engineering cost approach.

Compared to conventional tillage, conservational tillage is cheaper in almost all cases. Especially in oats and sunflowers, cost reductions are high and can reach 38 €/ha. Only in potatoes and sugar beet costs is it the other way round, with conservational tillage being up to 61 €/ha more expensive. Both crops are very sensitive to seed bed structure and to residual straw, which are general problems of conservational tillage. In grain and silage maize costs are lower for mulch seeding, but higher for no-till.

5.1.1.1.2 Methodological Issue: Better Expressiveness through Integrating Biophysical Data

The motivation for the integration of SOC-values simulated within a biophysical model was to replace the default values that are usually applied, with site-specific values. Popular sources of default values are the IPCC or the Cross-Compliance regulation of the 2003 reforms of the AGENDA 2000. Generally, SOC dynamics are influenced by weather, crop history, current crop, soil characteristics, natural SOC saturation level, soil management, crop management, and crop residue management. Out of this bulk of factors the IPCC takes into account climate (instead of weather), soil type, and crop residues, all of which are factors for which the IPCC has only defined a few categories, e.g. climate is categorised into tropical, sub-tropical, temperate or cool (IPCC, 2006b, p. 5.17 and p. 5.18). In contrast to the global IPCC, the Cross-Compliance is restricted to European climate conditions and it adds the factor current crop but neglects the factor soil type[82]. Yet soil management, site-specific weather and soil characteristics, and crop history are neglected in both.

---

[82] The main crop is attributed a humus consumption rate, while the crop residue is attributed a humus building rate in the case that it is left on field for decomposition (e.g. 280 kg/ha annual humus consumption for the grain and 100 kg/t for the cereal straw if left on field for decay). Humus is converted to humus-C and to SOC through fixed conversion factors.

With the biophysical EPIC-model site-specific SOC-values were simulated by SCHMID (2006b) according to natural conditions and management induced factors like tillage management, residue management, crop rotation, and crop history. Moreover, EPIC simulated the feedback reactions of the management on the development of crop yields. This is an additional and very valuable factor not obtainable from default databases like IPCC or the Cross-Compliance regulation. In order to accurately simulate natural conditions the model is run on a daily basis. So dates of agricultural activities had to be scheduled. This was carried out similarily to the procedure described by NEUFELDT (2005) utilizing phenological data from meteorological services in order to fix management dates like fertilization, seeding, or harvesting.

The data exchange of EPIC with the economic model applied by this study was bidirectional. Before receiving simulation results from EPIC, the economic model had to generate steering parameters for EPIC: crop areas and the level of mineral and organic fertilization. The backward data exchange to the economic model asked for an interface to generalise the site- and crop rotation specific EPIC data[83]. While the number of crop rotations and combinations with management alternatives is potentially infinite, the number of simulations by EPIC had certainly to be limited. This limited number of simulations had to be generalised to cover the entire range. This generalisation was manifold. First, soil characteristics were reduced into fewer classes. Second, crops were categorised according to their effect on SOC, and a limited number of crop rotations defined by these crop groups were extracted. Third, crop residue management was categorised into five discrete classes. Other management factors (tillage) were not generalised, but maintained in their original form. Running the economic model, the simulated farms will then select one out of the potential crop rotations available at their site (their natural conditions) and the integration of site- and management specific SOC-values is finished. As the farms select one available crop rotation, a binary decision variable had to be integrated. This forced the conversion of the economic model’s original LP structure into a MIP-structure.

The above mentioned generalisation, like any generalisation, certainly omits some information. A statistical analysis as to how far the omitted information reflects

---

[83] The regional resolution was on Homogeneous Response Units (HRU), a geographical delineation defined by the biophysical working group of the INSEA project (see section 3.2.4).

dividing characteristics was not performed. To put it simply, it can be summarised that the following crystallized: grain maize, potato, sugar beet, sunflower, and rye react a lot more sensitively (higher yield decreases) to conservational tillage than other crops.

5.1.1.1.3 Methodological Issue: More Flexible Simulation of Biogas Production

Among the factors constituting the fixed costs of a biogas plant, the most important one is plant size. Here, plant size is defined by the capacity of the Combined Heat and Power (CHP)-unit and the fermenter volume. The applied substrates impact on the quantity of biogas and hence on the CHP capacity, and hence also on the necessary fermenter volume since substrates feature different recommended hydraulic retention times. The approach seeks to minimize the portion of fixed costs forced into the model. That is why a minimum or standard biogas design has been formulated for each of three potential CHP capacities (150 kW, 250 kW, and 600 kW). The design calculations rely upon the most efficient substrate being used, i.e. the substrate with the highest relation between energy and fermenter volume. It is only for this CHP and its correspondent fermenter volume that fixed costs are forced via a binary variable into the model, necessarily a MIP model structure. So, the approach taken here integrates only part of the fixed costs, while other fixed costs for any potential further unit of fermenter are added to the substrate costs. As such they are treated as quasi-variable costs. The installation of further units of fermenter can be revised every modelling period. This is certainly an unrealistic assumption since once they are established, fermenters will not be dismantled and rebuilt every now and then, but the premise does provide increased flexibility while constraining production through integrated fixed costs.

Biogas production was simulated to analyse its production potential in the EU-15. The production potential was analysed under different rates of heat commercialisation from the CHP unit. Electricity was valued at the prices stipulated in the German Renewable Energy Act and heat was valued at 38 ct €/l of oil equivalent. For each of the three CHP sizes an exemplary biogas plant was calculated based on assumed climate, substrate mixture, substrate costs, and heat commercialisation rate. In middle European conditions with a substrate mixture of 18% pig slurry, 42%

cattle slurry, and 40% maize and costs of 17.80 €/t[84] of maize the profitability of the biogas plants presents as follows: fermenter sizes are from 1,496 - 6,138 m^3, entailing investment costs from 465,000 - 1,608,000 €. At the assumed heat commercialisation rate of 30%, the annual revenue is from 224,000 € to 903,000 €. Assuming an imaginary salary (national values) the profit calculates as 104,000 € for the 150 kW plant and as 477,000 € for the 600 kW plant (excl. fertilizer costs, spreading costs for the effluent from maize, and agricultural subsidies). SCHÄFER (2006) calculated the profitability of a biogas plant with similar substrate mixture (63% pig slurry, 37% maize), but a smaller plant (100 kW) and only 10% heat utilization rate. He came to a profit of 22,500 € annually. According to Zeddies (in SCHMITZ et al., 2009, pp. 222 - 235) biogas plants based on free manure and with a certain rate of heat commercialisation achieve an extraordinarily high profitability. He estimated that for a 150 kW CHP biogas plant (100% manure, 30% heat utilization) the profitability amounts to 77,700 € annually. The profitability calculated in this study is above that one of the two cited studies. However, if transport costs for manure are excluded, as in our example, then the profitability for the biogas plant estimated by Zeddies increases to 109,400 € and is even above the profitability estimated here.

5.1.1.2 Modelling Results:

The modelling results are from the so-called EU- Economic Farm Emission Model (EU-EFEM). This model has been developed in the framework of this study. It is an economic-ecological farm level model of the type MIP. It evolved from previous model versions still on a different scale, and of a different scope, structure, and programming language. EU-EFEM allows the simulation of the most common agricultural productions found in the EU-15, plus conservational tillage and biogas production under different political framework conditions. “Artificial farms” are simulated each of them representing the regional average of the farms pertaining to a certain farm type. The “average farms” are calibrated to take up the deviation between the accountancy data from which they are drawn and the regional agricultural statistics. This is to allow the accurate extrapolation of average farms to regions, i.e. the simulated farms multiplied by an extrapolator factor represent 100% of the regional agricultural capacities.

---

[84] Corresponds to costs as in the East German NUTS-II-region of “Brandenburg-Nord” as medium to low cost region.

The modelling exercises executed within this study are limited in number. The intention is merely to show the model's functioning. So, simulations are limited to the economic and ecological reference (GHG emission levels) and to the scenarios: 1) increase SOC-accumulation by forcing conservational tillage; 2) force SOC-accumulation, providing a choice of several means; and 3) biogas production to decrease GHG emissions.

5.1.1.2.1 Reference Situation: Ecology

The ecological reference situation confirms agriculture as an important emission source. This is especially true for methane emissions which are mainly from the keeping of cattle and other ruminants. Enteric fermentation is the single largest emission source on EU-15 average. It is responsible for 32.4% of agricultural GHG emissions (in tCO_2e). Further important sources are manure management (23.9%), indirect (14.5%) and direct soil emissions (11.2%), and the production of synthetic fertiliser (8.9%). Minor sources are the consumption of diesel and the production of purchased feed stuffs.

For the entire EU-15 the emissions add up to 433.5 Mill tCO_2e. This value can be compared to other studies, e.g. by PÉREZ DOMÍNGUEZ (2006). He, by means of the partial-equilibrium model CAPRI, estimated the emissions for the same sources[85] at 330.7 Mill tCO_2e (for 2001). Further, he cited the emissions reported by EU member states to the UNFCCC within their reporting obligations under the Kyoto Protocol at 351.9 Mill tCO_2e (in 2001)[86].

Apart from overall emission, their regional (NUTS-II) distribution was analysed in the current study. On a per hectare basis, the highest emissions (Belgian region) are 16 times above the lowest (Swedish region) describing a wide range from 1.9 – 25.6 tCO_2e. Emissions are highest in the Netherlands, Belgium, and the Italian Po valley while emissions are low in Sweden, Portugal, and most of Finland and Spain. Again for comparison, in the above cited PÉREZ DOMÍNGUEZ (2006) the range for CH_4-emissions spans a factor of 50 between the lowest and highest value (5.0 - 267.0 tCH_4/ha) and a factor of 21 for N_2O (0.8 - 16.8 tN_2O/ha).

---

[85] Emissions from the production of synthetic fertiliser, the purchase of fodder and concentrated feedstuffs, and for diesel were disregarded as not simulated by CAPRI. The values from CAPRI were corrected for the United Kingdom which was not modelled by EU-EFEM.

[86] Values reported to the UNFCCC and CAPRI values include emissions from the cultivation of histosols.

Generally, the wide range of regional GHG emissions might be explained by their strong correlation to ruminant numbers and fertilizer application rates, two determinants that show a large intra-European variation. The fertilizer application rates might be overestimated by EU-EFEM as they simulated by long-term yield functions and thus can deviate from statistical data on yearly fertilizer sale. However, the reference situation seems robust and conforms roughly to other literature sources.

5.1.1.2.2 Scenarios 1 and 2: Stimulating SOC-Accumulation

The underlying hypothesis to scenarios 1 and 2 was the assumption that the agricultural sink function provides effective and rapid mitigation. The greatest potential is assumed for SOC-accumulation on agricultural land. In this study only cropland as part of agricultural land which remained cropland was analysed. Land-use change and carbon accumulation on grassland were disregarded[87]. In scenario 1, SOC-accumulation through forced minimum shares of conservational tillage on arable land (in the form of mulch seeding and no-till) was analysed. In scenario 2, minimum SOC-accumulation rates through a set of optional measures were forced.

Summarising the **findings of scenario 1**, it turned out that all three forced minimum conservational tillage shares (40%, 70% and 100%) can be complied with by farms. Moreover, in the majority of cases, over-accomplishment is frequent (logically except if 100% are forced). This circumstance is also reflected in the scenario’s economic impacts, where, on average, gross margins turn negative only for forced shares above 80%. Because of lower production cost, the average adoption rate of conservational tillage is 56% free of any obligation. In contrast, if 100% of conservational tillage are forced, the average gross margin changes by -20 €/ha compared to the reference situation without conservational tillage and by -13 €/ha compared to a situation where conservational tillage is a free option. The negative impact on gross margins is mainly due to lower yields under conservational tillage especially in crops that require fine seed beds like sugar beet.

On a regional level, the decrease of gross margins can be significantly above -20 €/ha. In this respect the strongest affected region is Liège (Belgium), with

---

[87] The reasons are that EU-EFEM is an annual model and that grassland offers few options to stimulate SOC accumulation.

approximately -260 €/ha. On a farm level, the decrease reaches approx. -350 €/ha for arable farms in Liège. In the same region and scenario case, the gross margin changes by ±0 €/ha for intensive livestock farms, which indicates how large intra-regional variability can be. On average, however, arable and mixed farms are affected more strongly than intensive livestock and forage growing farms. The main reason is seen in the relatively high shares of maize and sugar beet in the crop rotation of the first mentioned; and maize and sugar beet are humus-demanding crops for which EPIC simulated high yield decreases due to conservational tillage.

From an ecological perspective, forcing 100% conservational tillage changes the SOC-pool from -28 kg/ha in the reference situation to +4 kg/ha. This is a mitigation of 32 kg/ha which reduces even further to +2 kg/ha if conservational tillage were allowed in the reference. For the entire EU-15, this adds up to a mitigation of roughly 1 Mill t of SOC for this strongest scenario case of 100% conservational tillage (freeing of -888,700 t in the reference plus the accumulation of +121,600 t in 100% forced conservational tillage).

So, while economic losses are moderate on average (although not so on a farm level), the ecological benefits remain disappointingly low throughout all scenario cases. The default values for humus dynamics in the Cross-Compliance regulation or the analysis by BOYLE (2001), for example, would have suggested something else. Boyle writes that soils contain three times more carbon than vegetation and twice as much as the atmosphere. Against this background scenario 2 was formulated, forcing farms to SOC-accumulations while offering also measures other than conservational tillage, e.g. "*modification of crop rotation*" or "*more straw left for field decay*".

Summarising the **findings of scenario 2**, the ecological targets were achieved widely, only widely and not completely because a number of regions could not comply with the scenario obligations and thus did not accumulate the forced 0.5 t/ha or 1.0 t/ha depending on the scenario case. As over-accomplishment was not found, the overall SOC-accumulation corresponds to the area multiplied by the accumulation rate.

To comply with the scenario obligations, farms do not prefer a certain scenario measure. Rather all measures are adopted, albeit at very different rates, and thus contribute to keeping scenario costs as low as possible. Only in 4.1% or 1.8% of regions (scenario case 1 and 2) is the forced SOC-accumulation achieved without implementing any of the measures. The combination of all three measures is the most common mode of implementation. If 1.0 t of SOC/ha of accumulation is forced, for example, the modification of crop rotation is expressed by an increase in the share of non-cereals (other than maize or tuber crops) by 6%-points, mainly at the expense of cereals (maize and tubers are nearly unaffected), conservational tillage is increased to 62%, and the share of straw left for field decay is increased by nearly 10%-points to approx. 70%.

With respect to economic impacts, the gross margin increases by up to 15 €/ha in single regions (compared to the reference situation without conservational tillage). The maximal decrease on a regional level is -150 €/ha under the forced 0.5 t of SOC/ha, or -250 €/ha under the forced 1.0 t of SOC/ha. In the first and weaker scenario case, 17 regions do not return a valid solution and in the second, 25 regions do not. These high numbers should be compared to scenario 1, where all regions returned a solution. On a farm level, there are farms that lose up to 350 €/ha while there is no trend for disadvantages to a certain farm type. One general correlation has been identified: seemingly in regions where the crop rotation is modified strongly towards humus accumulating crops, scenario costs are highest.

5.1.1.2.3 Scenario 3: Biogas Production Potential

It is known that the rate of heat commercialisation is a critical factor of profitability in agricultural biogas plants (e.g. SCHMITZ et al., 2009, pp. 222 – 235). This is in line with the results for the biogas production potential simulated in the present study. The potential increases with the rate of heat commercialisation analysed in three different scenario cases (0%, 50%, and 100% of heat commercialisation). Further, the effects of relieving the obligation to at least equilibrate its humus balance, as stipulated by the Cross-Compliance regulation, was analysed in a fourth scenario case.

From the economic point of view, through biogas production the total profits of farms in the EU-15 can be increased by 1.6 Bill € if 0% of thermal energy is commercialised. If 100% of thermal energy is commercialised the profits can be increased by 9.2 Bill €. If farms are relieved of the obligation to at least equilibrate the humus balance, profits are higher by another 0.9 Bill € (compared at the scenario cases of 50% heat commercialisation).

The production potential is from 108 - 360 TWh for electricity and from 106 - 293 TWh for thermal energy. With respect to the regional distribution of biogas production, it is concentrated in France, Germany, Denmark, South Sweden and North-East Spain. The number of biogas producing regions is 41 at 0% of heat commercialisation and goes up to 82 at 100% of heat commercialisation.

In this study the utilization of manure as biogas substrate is mandatory. At the lowest realised production potential 19.2% of manure and at the highest one 60.2% of manure are used as a biogas substrate. This also has a side effect on animal production, which increases by 91,800 and 193,400 Livestock Units (LU) in the scenario cases. The exploited production potential also binds significant shares of agricultural land. In the weakest scenario case 8.1% of grassland and 4.9% of arable land are dedicated to substrate production. In the strongest scenario case 28.7% of total grassland and 18.5% of total arable land are necessary equal to 22.3% of total agricultural land.

If farms are relieved of the Cross-Compliance regulation, energy production from biogas goes up by 24 TWh(el) and 11 TWh(th): equal to an increase by 9.4% and 10.5%. The increase in biogas production is not the only effect. Further, maize as substrate gains in absolute and relative significance. This can be read from the share of total arable land, which is nearly exclusively maize. It jumps from 13.0% to 18.9%. At the same time the utilization of manure and grassland is not expanded. This circumstance is of extraordinary relevance to arable farms, which over proportionally increase biogas production. Typically they already cultivate high shares of humus demanding crops, limited by the Cross-Compliance Regulation and they have limited grassland areas and/or manure.

Validation of the obtained results is difficult, since biogas production is a rather new production branch, and as such its potential might not yet have been fully exploited. Furthermore, the German “Renewable Energy Act (EEG)” was assumed to apply to the entire EU-15, which is not the case in reality. Because German biogas production has a longer history, and due to the above mentioned reasons regarding the validation on a European level, validation of the results against German statistics is done. For Germany, the simulated biogas production potential of around 30 TWh corresponds roughly to the potential of 34 TWh stated by the FNR (2008).

The significant requirement for agricultural land when exploiting the biogas production potential has already been mentioned. Up to 22.3% of agricultural land would be dedicated to the cultivation of biogas substrates. Unlike the utilization of manure, this would have a strong impact on other agricultural production activities. The impacts on other regions or even countries or on agricultural prices unfortunately cannot be simulated by the micro-economic model applied in this study. But Zeddies and Gamer (in SCHMITZ et al., 2009, pp. 9 - 99) extrapolated trends of food and feed demand, population growth, yield and agricultural land development among others in order to predict the available agricultural area for non-food purposes. They made the assumption of 100% self-supply of food/feed on a national level, abolished mandatory set-aside regulation, and abolished export subsidies. For the EU-15 they predicted a considerable land potential fluctuating between 14 and 17% in the years 2005, 2010, 2020. This would nearly suffice to host the biogas production simulated by this study. However, their values predicted for the entire world[88] looked really different: 13.8% in 2005, 4.0% in 2010, -5.4% in 2020, and -25.7% in 2050. This would mean a significant lack of agricultural land in the years to come and certainly entail higher agricultural prices.

Whether European farmers would exploit the land potential to produce food for export or to cultivate substrates for biogas production depends on the price relation (e.g. for food and renewable electricity). Zeddies and Gamer assume food production will be favoured. The difference in the prices utilized in the present study (reference years 2000 – 2003) and prices predicted for the years up to 2016 is striking. International research institutes, for example, assume a price stabilization at around 220 US$/t of wheat (SCHMITZ et al., 2009, pp. 9 - 99) compared to 120 €/t respective 168 US$/t in EU-EFEM (exchange rate EUR to US$ = 1:1.40).

Moreover, even if Europe’s agricultural land potential was not used for the production of food for export, it still cannot be expected that the entire land potential indicated by Zeddies and Gamer of 14 - 17% would be taken up by biogas plants. In the light of the 2020 policy targets formulated by the EU for bio-fuels and bio-energy, they assume that the largest consumer countries alone would eat up 10% of the total land area, each for bio-ethanol and bio-diesel (already taking into account substitution effects from by-products).

---

[88] This refers to the 134 countries considered in their analysis.

5.1.1.3 Abatement Costs: Comparison

In the following the mitigation costs from the three scenarios are compared to each other and to literature values. Mitigation costs are indicated in €/tCO_2e, whereby the conversion of tonnes of SOC mitigated to tonnes of CO_2e mitigated is with the factor representing the C-content (molecular weight) of CO_2: 44/12.

In scenario 1 the achieved mitigation was disappointingly low at most 1.0 Mill t of SOC or 3.7 Mill tCO_2e for the EU-15. In contrast, scenario and thus mitigation costs only became present beyond a forced conservational tillage share of 80%, since in the beginning the scenario option to do conservational tillage taken by some farms outweighs the obligation of all farms to do so. When this is compared to a reference situation in which conservational tillage is allowed, scenario costs become present with a forced share of roughly only 40%. They add up to 23 Mill, 99 Mill, and 1,445 Mill € for the EU-15 if 40%, 70%, or 100% of conservational tillage are forced. In relation to the minimal quantities of mitigated carbon, mitigation costs are -145, 1,825, and 416 €/tCO_2e[89] which means, that a mitigation gain is firstly realised. Despite the situation regarding mitigation gains the implementation of this scenario cannot be recommended as mitigation quantities do not compensate for the effort involved and as single farms have to suffer far higher losses than the average.

In the scenario 2 the mitigation was from 93.2 - 181.2 Mill tCO_2e. Scenario costs occur in all scenario cases. They total to 642 Mill € and 2,011 Mill € for the EU-15 where 0.5 t of SOC/ha and 1.0 t of SOC/ha are forced. The mitigation costs can thus be calculated as 6.89 €/tCO_2e and 11.09 €/tCO_2e. Although these abatement costs are quite low, the result looks much less attractive if we take the considerable number of regions that simply do not return any solution because of scenario obligations that are too strong into account. If they are taken into account[90], then mitigation costs change from originally 6.89 € to 74.66 € and from 11.09 € to 65.01 € per tCO_2e.

In scenario 3 the mitigated emissions are calculated as being the sum of the positive impacts from the replacement of fossil fuels and energy recovered from biogas and improved manure management, minus the emissions related to synthetic

---

[89] The awkward situation of decreasing costs with increasing scenario obligations can be explained by the exclusion of regions where no valid solution is returned.

[90] Mitigation costs can even go down from the weaker to the stronger scenario case since different farms are included into both calculations.

fertilisation of biogas substrates. For the EU-15 the mitigation is from 46.7 Mill tCO_2e where 0% heat is commercialised (lowest production potential) to 263.1 Mill tCO_2e in case 100% heat is commercialised (highest production potential). Compared to scenario 2, the mitigated quantity is only half in scenario 1 when comparing the lowest mitigations to each other, and it is around 140% when the strongest scenario cases are compared; however, this was achieved by only 82 biogas producing regions here.

In the biogas scenario, mitigation costs were also calculated with subsidies included in the calculation in order to better reflect overall costs for the society (although excluding reactions on labour prices etc.). Mitigation costs are close to 30 €/tCO_2e if no heat can be commercialised, but turn into -5.10 €/tCO_2e (mitigation gains) if all heat can be commercialised. Compared to the lowest mitigation costs in scenario 2 of 6.89 €/tCO_2e, mitigation costs are higher here if no heat can be commercialised and the situation only turns around at heat utilization rates above 50%. In this context three things should be remembered: First, the values of emission reduction from biogas production are based on the assumption that heat would replace heating oil. Second, when forcing SOC accumulation rates, like in scenario 2, many regions do not comply with the scenario obligations. Third, it is possible to combine a SOC-scenario with the biogas production scenario. However, the simulation of this combination was impossible due to solver limitations (too many integer variables).

5.1.1.3.1 Abatement Cost Comparison to Literature Values

As in the current study, DECARA and JAYET (2009) also simulated marginal CO_2-abatement costs of agriculture within a linear programming model. Their analysis was for the EU-24. They forced different shares of CO_2-reduction on the 2004 emission situation. Where a 10% reduction was forced, the abatement costs were at 41 €/tCO_2e and increased to 300 €/tCO_2e where a 40% emission reduction was forced. At around 60%, emission reduction levels out rapidly. Moreover, regional abatement costs showed a wide variation similar to the present study. A thorough comparison between both studies would be unproductive as DeCara and Jayet restricted mitigation measures to changing animal numbers, animal feeding, and crop area allocation while neglecting biogas and SOC-accumulation. Moreover, that the current study did not analyse an emission reduction relative to the initial emission level (or an emission tax) although this was structurally integrated into the model.

Although limited in its validity to Germany, a study performed by the VON THÜNEN INSTITUTE (vTI, 2008) provides a better basis for comparison. The von Thünen Institute (vTI) estimated mitigation costs in biogas production and other renewable energy branches based on biomass and included substitution effects through by-products. If applicable, subsidies were included like in the present study.

Biogas production was analyzed for four different plants, among them one run on pig slurry exclusively. Energy recovery is in a CHP with a heat recovery rate of 30%. For this plant the vTI indicated the mitigation costs 52 €/tCO_2e. At the same heat utilization rate[91], the present study found the mitigation costs to be 16 €/tCO_2e. In contrast to the modelling results of the current study, the estimate by the vTI is based on pure micro-economic considerations. Lower mitigation costs in the model might be due to the optimization of all three levels of optimality (minimal cost combination, optimal intensity, and optimal production program). Further, the result of the current study is for the entire EU while the vTI result is only for Germany with assumed production costs of 28 €/t of maize, which are thus often enough above EU-level.

The vTI also analyzed further biogas plants, with different heat utilization rates, different substrate mixture, and different energy recovery. In the present study mitigation costs reached a maximum 29 €/tCO_2e (where no heat is utilized). The vTI, in contrast, found extremely different results. For example, if biogas production is not based on manure or no heat is utilized they indicate mitigation costs noticeable above 200 €/tCO_2e. If the substrates do not include manure but only renewable crops, the mitigation costs are stated at 267 €/tCO_2e (although there is 30% heat utilization) and if no heat but only electricity is sold they are 378 €/tCO_2e (Table 92 Utilization: “CHP” and “Electricity”).

---

[91] For reasons of simplicity a linear relation between the scenario cases 0% and 50% rate of thermal energy relation was assumed.

Table 92: Key Data (rounded) of Renewable Energy Production in Germany

Source	**Utilization**	**Net-Energy***	**Emission Mitigation**	**Mitigation Cost****
		(MWh/ha)	(tCO_2e/ha)	(€/tCO_2e)
Wood chips	Heating	34	10	-11
	CHP	38	13	29
Biogas	Electricity	10	6	378
	CHP	15	7	267
	Fuel	30	6	173
	Manure CHP			52
Biodiesel	Fuel	11	3	175
Bio-ethanol (wheat)	Fuel	6	2	459

Source: Estimated from vTI (2008), Figure 6.2 and Figure 6.3
** Net Energy = Gross Energy – Conversion Energy + Energy saved through by-products*
*** Based on prices of 180 €/t of wheat, 80 €/t TM of wood chips and 115 €/t TM if including land costs, 28 €/t FM of energy maize, and 340 €/t of rapeseed.*

Moreover, the vTI compared the mitigation costs of biogas production to other bio-energy branches using biomass. The comparison showed that the mitigation costs in biogas production lie in centre field. Bio-ethanol, for example, entails mitigation costs of 459 €/tCO_2e. Biodiesel entails lower mitigation costs, which are at 175 €/tCO_2e, due to higher net energy yields per hectare. But bio-ethanol in particular has been subject to criticism for several years because of its doubtful contribution to greenhouse gas mitigation and the hope in bio-fuels is on the so-called second generation fuels. In second generation fuels, biomass residues or other slowly decomposable biomasses (e.g. wood waste or straw) are exploited through pyrolysis or by means of enzymes in biogas digesters. The European Biofuels Technology Platform (BIOFUELSTP, 2009) has published a well-to-wheel consideration of different fuels. In conventional fuels, well-to-wheel means the entire chain from the oil well through the gas station through the engine to the wheel. They indicated the associated GHG emissions for diesel and gasoline at roughly 160 gCO_2e/km, for first generation bio-ethanol made from wheat at roughly 90 gCO_2e/km, for second generation bio-ethanol made from wheat straw at roughly 20 gCO_2e/km, and for second generation synthetic fuel (pyrolysis) made from biomass at below 10 gCO_2e/km. So, summarizing, the developments on second generation fuels might make them look better in comparison to biogas production, but whether they can compete or not in mitigation costs with biogas from manure based systems and high heat utilization rates still has to be demonstrated.

5.1.1.3.2 Conclusions

The study brought forth several new methodological approaches being applied for the EU-15 but being expandable to the EU-27. One of these was the approach for estimating variable production costs. It delivered cost estimates on the high regional resolution of NUTS-II. Through merging accountancy and engineering cost data, crop specific and region specific estimates were made that might find application also in other (micro-economic) studies on European agriculture and might be a real alternative to the application of standard gross margins. However, transfer to other sectors is difficult or impossible, since the approach is based on a number of agriculture specific considerations. Because of the wide range of values found, although relativised through the wide range of production conditions in the study region, validation with further empirical data from EU member states would be recommendable.

With respect to a second new approach, the integration of biophysical data into the micro-economic EU-EFEM, it turned out that the high SOC-accumulation expected following the introduction of conservational tillage could not be achieved equally over all agricultural areas in the study region. Considerable SOC-accumulation is only achieved if conservational tillage can be combined and locally substituted with other measures, but still the accumulation is delivered by a narrow majority of regions. Already these regions can contribute to mitigation through SOC-accumulation in a dimension that is comparable to the mitigation of the biogas plants simulated for the EU-15. Despite its belittled contribution to SOC-accumulation, conservational tillage is done on 56% of arable land in free competition, because of lower costs.

Considerable mitigation of up to 180 Mill tCO_2e could be achieved at small mitigation costs of around 11 €/tCO_2e by some compliant regions if forcing 1.0 t/ha of SOC-accumulation. The costs increase significantly if all regions, also regions in counteracting conditions, would be forced. In the biogas scenario, found mitigation costs were also low and at around 16 €/tCO_2e if a realistic heat utilization rate of 30% is assumed. In the European Emission Trading System (EU-ETS), which has been running now for several years (1st phase was launched in 2005), and where the six main polluting industrial sectors are included, prices have lately settled at around 20 €/tCO_2e roughly.

So, the enforcement of minimum shares of conservational tillage could not deliver the expected impact, and the enforcement of minimum SOC-accumulation rates per hectare is not feasible from a political point of view. Enforcing minimum SOC-accumulation rates just involves exuberant control effort, both from an administrative and farmer point of view. For the farmer there is additionally the risk that although he might have modified crop rotations towards humus accumulating crops and have expanded conservational tillage, still the desired effect might not occur due to adverse natural conditions in a specific year or counteracting soil characteristics.

The path taken by the Cross-Compliance regulation seems more promising. There, default values of humus dynamics based on the determinants “cultivated crop” and “biomass input to soils through straw” are defined. An in-depth analysis of the SOC-values applied in the current study, and which are from the biophysical EPIC-Model, would be desirable in view of a potential adjustment of Cross-Compliance values or an identification of additional determinants at which to fix expressive and accurate default values. In the latter case it should be kept in mind that default values should be interpretable to farmers so they can modify their farm management if valuable/necessary. Above all, it should be kept in mind that SOC-accumulation is sensitive to external changes like tillage scheme and that the entire process is invertible.

On a general level, soil carbon sequestration still is to be evaluated conclusively. Its potential is large and it also can be exploited if promoted the right way and, in contrast to energy crops grown for bio-energy recovery (also cultivated energy wood), it is not a competing usage to conventional agricultural production. Further, it does not promote monocultures since it is compatible with a number of the currently dominating crops.

The situation is somewhat different for the analysed biogas production potential. Although in this study biogas production was necessarily bound to the utilization of manure as substrate, the simulated area requirement was above 22% of total agricultural land where the highest potential was realised. So, this would certainly compete with conventional agricultural production, especially in the light of global agricultural land shortage, predicted at 5% of available land by 2020. The highest simulated production potential is, however, rather hypothetic since it assumes a heat utilization rate of 100%. This value is far from what can be expected for average agricultural biogas production. Only with more “energy villages” or large biogas plants paying off the preparation of biogas for feed-in to natural gas networks might this target come closer.

The focus of political incentive schemes for biogas production should be on biogas plants with high shares of heat utilization and high shares of manure in the substrate mixture. Abolishment of the bonuses for energy crops has already been recommended by other studies. Comparable low mitigation costs to biogas plants with high heat utilization rates and solely manure substrates are not achieved by the popular bio-fuels, especially not by bio-ethanol, but also not by biodiesel. In bio-fuels the development of second generation fuels looks promising and might modify the picture as they are expected to emit only one quarter or even less carbon dioxide than current bio-ethanol gained from wheat. Yet it will be several years before they will only be ready for the market.

6 Summary/ Zusammenfassung

The present study's goal was to develop and apply analytical tools to describe the economic and ecological impacts of greenhouse gas mitigation measures. Therein, the study restricts to agriculture and as such to a sector that potentially takes a double function in mitigation strategies. On one hand, agriculture can mitigate emissions from agricultural sources like reducing consumption of fossil fuels or optimizing fertilizer application. On the other hand, agriculture can accumulate atmospheric carbon dioxide in soils and in this sense operate as carbon sink. Moreover, agriculture can be a producer of bio-energy gained from biomass. This bio-energy production, however, takes an extraordinary position, since the cultivation of bio-energy plants per se does not contribute to emission mitigation, but only behaves climate neutral. A positive impact on climate only installs at those spots where fossil fuels are displaced by bio-energy and thus not necessarily within agriculture itself.

In the analysis of the economic-ecological impacts, a mixed-integer programming model was applied. There, virtual farms, equal to those farms that would be typical for any of the far above 100 NUTS-II regions in the EU-15, were optimized. Starting point are up to four virtual farms per region that are extrapolated to represent the agricultural production of a region with 100% exactitude. Based on earlier model versions covering maximally Germany, the model was expanded to cover the EU-15 and site-specific SOC-values were integrated. In this context essential methodological developments had to be made.

Firstly, the data gap "production costs in the EU-15" had to be bridged. It should be the objective to get production cost data on regional or better farm level. In the EU-15, however, production cost data is rare and only standard gross margins as provided by FADN could be applied that, however, do not achieve complete regional coverage on NUTS-II level. As cost values besides revenue values are an essential input to the economic part of the model, the model's quality is finally predefined by the quality of the cost data. So, a new approach was developed that allows estimating variable production costs on NUTS-II level.

The approach draws on data from KTBL and FADN. KTBL is a standard work for the deduction of production costs which defines costs per production activity and also production activities per culture. FADN is a network that collects accountancy data through surveys from European farms on a regional resolution comparable to NUTS-II. Combing these two data sets crop specific default costs can be calculated. The validity of KTBL restricts to Germany, where KTBL surveys selected farms. In the presented approach, the limited geographic validity of KTBL is balanced by joining in FADN data. FADN presents data in anonymous form, but indexed for regional and farm type affiliation. Due to accountancy data usually not assigning costs to single crops, FADN data alone and similar to KTBL data is not sufficient. Through a combination of both datasets, however, crop specific estimates of production costs for all regions in the EU-15 were done.

The developed approach can best be circumscribed by a 1:1-transfer of the cost relation between crops according to KTBL to the cost values according to FADN cost items. For the cost item “contract work”, however, also KTBL does not define crop specific costs, because contract work costs are rather farm than crop specific. To this cost item a different method following a decision tree was applied.

The estimates generated by the approach show a wide range. In winter wheat, for example, costs are from 98 to 740 €/ha within the EU-15. However, this range corresponds to the range of production conditions and intensities prevailing in the EU-15, wherein “contract work”-costs are the main determinant. In-depth validation of the estimates could not be performed because of the lack of values on which to base a comparison. Nonetheless, the generated estimates are assumed to find great interest in agricultural research. Also the European Commission is funding a study on the deduction of production cost estimates from FADN accountancy data (FACEPA, 7th Framework Program).

Apart from the deduction of production costs, the quantification of the sink function of agricultural soils represented a major challenge. In the global standard work for the calculation of greenhouse gas emissions, the guidelines of the Intergovernmental Panel on Climate Change (IPCC), it is recommended to utilize rather rough emission factors in the quantification of the sink function that differ only between continents and a few soil types. In this study, a more accurate depiction of the sink function was achieved by applying site-specific values from the biophysical EPIC model. To integrate the site-specific EPIC values into the region-specific model utilized in the study, and also to balance the insufficient number of EPIC simulations, EPIC data was generalized. In the result, these values are still more detailed and expressive than the IPCC emission factors.

Out of the selection of agricultural measures to stimulate SOC-accumulation, namely conservational tillage, increased input of organic matter, and crop rotational modifications, a scenario was developed that forces conservational tillage. Globally, this measure is attributed a large potential. Minimum shares of conservational tillage per farm were inserted as constraints. These were 40%, 70%, and 100%. In the result, it turned out that all farms in the EU-15 could comply with such constraints. With forced shares exceeding 80% economic losses install on average. The main reason is the incompatibility of some current crop rotations with conservational tillage. First of all, this applies to crop rotations with large shares of sugar beet. Among the analysed farms the range of economic scenario impacts is very wide due to site-specific factors, different crop rotations and farm structures. In comparison to the average loss of 20 €/ha in case of 100% of forced conservational tillage, single farms suffer from a loss of 350 €/ha (arable farm, Liège, Belgium).

Despite the large potential, soils accumulate potentially three times as much carbon as vegetation and two times as much as contained in the atmosphere, the scenario measures entail an accumulation of only 32 kg/ha. For the EU-15, this marginal amount adds up to an accumulation of roughly 1.0 Mill t of SOC equivalent to 3.7 Mill tCO_2. On top of that, reversibility of soil carbon accumulation is an issue. Against the background of marginal accumulation and partially extreme economic losses, policy is recommended to dispense from a forced minimum share of conservational tillage as an instrument for climate protection.

In a second scenario, motivated by the low SOC-accumulation in the first scenario, minimum SOC-accumulation rates were constrained. For compliance, farms choose from all those agricultural measures which stimulate SOC accumulation, i.e. besides conservation tillage also increased soil incorporation of organic matter and shift of crop rotations towards humus accumulating crops. In the scenario the economic impacts of forcing 0.5 respectively 1.0 t C/ha of arable land were analysed. The results showed that such rates could not be achieved by all farms. This concerns 17 respectively 25 of a total of more than 100 analyzed regions. Nonetheless, accumulation adds up to 181 Mill tCO_2 for the remaining regions. Policy, however, should also withdraw from a regulation forcing minimum SOC-accumulation. Main reason is the difficulty of monitoring which would be required on site level. Moreover, farmers would not dispose of success guarantee for such ventures due to the multiple determinants (e.g. weather) being out of their control.

The mitigation costs are 70 €/tCO_2 in the event of a forced minimum accumulation rate of 1.0 t C/ha in average. If only those regions are considered in which the minimum accumulation rates can be achieved, then the mitigation costs are only 10 €/tCO_2. This is a competitive value taking into account that European emission reduction rights (Assigned Amount Units, AAU) are currently traded at around 20 €/tCO_2e. Because of the large mitigation potential of the scenario and the small mitigation costs, the flexible combination of agricultural measures to stimulate SOC-accumulation as in the scenario, thus is attractive although the difficult monitoring. Designing effective political instruments, the humus balance as stipulated in the Cross-Compliance regulation represents a prefect starting point. The default humus accumulation rates defined there could be refined through EPIC SOC values.

Besides the scenario on SOC-accumulation, the study analyzed biogas production with electricity recovery in a combined heat and power (CHP) unit. In this third scenario, different utilization rates for accruing waste heat were assumed (0 – 100%). Utilized waste heat is assumed to replace heating oil. According to the simulation results, European agriculture could increase yearly profits through biogas production by 1.6 to 9.2 billion € depending on scenario case. The Cross-Compliance regulation prohibiting a (calculated) decrease of humus balance on each farm, thereby limits biogas production. Relieving this regulation would enhance profits by another billion Euro. In this best case scenario, the contribution to climate change mitigation adds up to 47 respectively 263 Mill tCO_2 depending on the rate of waste heat utilization. On the macro-level, i.e. excluding the subsidy comprised in the feed-in tariff, a mitigation gain of 5 €/tCO_2 would install if utilizing 100% of waste heat occur, if 100% heat are utilized and mitigation costs of 30 €/tCO_2e if 0% heat are utilized.

Currently discussed in the context of agricultural bio-energy production, the competition for agricultural land with food and feed production is an issue. Tapping the full biogas production potential in agriculture, which means if 100% of waste heat could be utilized, then 28.7% of grassland and 18.5% of arable land would be bound, although the model constrains biogas production to utilize animal manure as co-substrate. The impacts of this competition on agricultural prices cannot be simulated by the applied farm level model EU-EFEM, but an equilibrium model would be necessary. In the study alternatively literature sources were cited that predict agricultural prices based on different development paths considering bio-energy production. With respect to policy recommendations, it is concluded from the study results that subsidies of biogas production should focus on promoting production which is based on animal manure and on the utilization of waste heat in order to alleviate the area competition like, for example, it is fired by the bonus paid for renewable biomasses in Germany, for example.

Zusammenfassung

Die vorliegende Studie diente dem Ziel analytische Werkzeuge zur Abbildung ökonomischer und ökologischer Auswirkungen von Treibhausgasminderungsmaßnahmen weiterzuentwickeln und anzuwenden. Die Studie betrachtet dabei lediglich die Landwirtschaft und damit einen Sektor der bei der Emissionsminderung potentiell eine Doppelfunktion einnimmt. Zum einen, kann die Landwirtschaft eigene Emissionen verringern, etwa durch geringeren Verbrauch fossiler Energieträger oder optimierte Düngeranwendung. Zum anderen, kann sie atmosphärisches Kohlendioxid in Böden anreichern und damit als Senke fungieren, d.h. CO_2 binden. Darüber hinaus kann sie Bioenergie aus Biomasse bereitstellen. Die Bioenergieerzeugung nimmt allerdings eine Sonderstellung ein, denn der Anbau von Bioenergiepflanzen ist lediglich klimaneutral und trägt per se noch nicht zum Klimaschutz bei. Ein positiver Beitrag zum Klimaschutz entsteht erst dort, wo fossile Energieträger durch Bioenergie ersetzt werden, das heißt nicht zwangsweise in der Landwirtschaft selbst.

Zur Analyse der ökonomisch-ökologischen Auswirkungen wird ein gemischt-ganzzahliges Programmierungsmodell eingesetzt. Dort werden virtuelle, landwirtschaftliche Betriebe, wie sie typischerweise in den weit über einhundert NUTS-II-Regionen der EU-15 zu finden sind, optimiert. Ausgehend von jeweils bis zu vier optimierten Betrieben je Region, werden die Simulationsergebnisse derart hochgerechnet, dass die landwirtschaftliche Produktion einer gesamten NUTS-II-Region zu 100% repräsentiert wird. Aufbauend auf maximal auf Deutschland begrenzter, früherer Versionen des Modells, fand hier eine Ausdehnung auf die EU-15 statt und standortspezifische Werte der Boden-C-Dynamik wurden integriert. Dazu waren wesentliche, methodische Weiterentwicklungen notwendig.

Erstens musste die Datenlücke „Produktionskosten in der EU“ geschlossen werden. Dabei sollte es das Ziel sein Produktionskosten auf Regions- oder gar Betriebsebene zu bekommen. In der EU sind Produktionskosten jedoch wenig verfügbar und die Standarddeckungsbeiträge des FADN hätten alternative verwendet werden müssen. Diese allerdings erreichen keine volle Abdeckung sämtlicher NUTS-II-Regionen. Da Produktionskosten neben -erlösen den zentralen Input des ökonomischen Teils des verwendeten Modells darstellen, ist deren Qualität letztlich

ausschlaggebend für die Qualität des Modells. Es wurde daher ein neuer Ansatz entwickelt, der es erlaubt variable Produktionskosten auf Regionsebene zu schätzen.

Der Ansatz greift auf Daten des KTBL und FADN zurück. KTBL ist ein Standardwerk zur Ableitung von Produktionskosten in dem Kosten je Produktionsschritt und weiter Produktionsschritte je Kulturart definiert werden. Das FADN ist ein Netzwerk das Buchführungsdaten von europäischen Landwirtschaftsbetrieben auf NUTS-II-Ebene erhebt. KTBL ist nur für Deutschland einsetzbar, denn nur dort erhebt das KTBL Netzwerk Daten bei ausgesuchten Betrieben. Im entwickelten Ansatz wird diese begrenzte, geografische Gültigkeit durch die FADN Daten ausgeglichen. Die Daten werden anonymisiert aber nach Region und Betriebstyp indiziert angegeben. Weil in der Buchführung generell keine Zuteilung von Kosten auf Kulturarten erfolgt, sind die FADN Daten ebenso wie die KTBL Daten alleinig nicht hinreichend. Durch eine Kombination beider Datenbanken allerdings, konnten kulturartspezifische Kostenwerte für sämtliche Regionen der EU-15 generiert werden.

Der entwickelte Ansatz kann am einfachsten durch eine 1:1-Übertragung des Kostenverhältnisses zwischen den Kulturen nach KTBL auf die einzelnen Kostenpositionen nach FADN umschrieben werden. Bei der Kostenposition „Lohnarbeiten“ allerdings, weist auch KTBL keine kulturartspezifischen Standardwerte aus, denn diese sind letztlich nicht kulturart-, sondern betriebsspezifisch. Für diese Kostenposition wurde daher eine alternative Schätzmethode entwickelt und angewendet.

Die mittels des Ansatzes gewonnenen Schätzwerte weisen ein weites Spektrum auf. Bei Winterweizen, zum Beispiel, reichen die Kosten in der EU-15 von 98 bis 740 €/ha. Letztlich entspricht dies aber dem Spektrum der Produktionsbedingungen und -intensitäten in der EU-15, wobei Kosten für „Lohnarbeiten“ der bedeutendste Faktor ist. Eine tiefgehende Validierung des Ansatzes war aufgrund fehlender Vergleichswerte nicht möglich. Dennoch werden die Schätzwerte wohl großes Interesse in der Agrarforschung hervorrufen. Auch die Europäische Kommission fördert derzeit eine Studie zur Ableitung von Produktionskosten aus FADN (FACEPA, 7. Forschungsrahmenprogramm der EU).

Neben dem Herleiten von regionalen Produktionskosten stellte die Quantifizierung der Senkenfunktion landwirtschaftlicher Böden eine zweite, große Herausforderung dar. Im globalen Standardwerk zur Berechnung von Treibhausgasemissionen, der Richtlinie des Intergovernmental Panel on Climate Change (IPCC), wird zur Quantifizierung der Senkenfunktion von Böden die Verwendung relativ ungenauer Emissionsfaktoren, die lediglich zwischen Kontinenten und ein paar wenigen Bodentypen unterscheiden, empfohlen. Im Rahmen der Studie wurde eine bessere Abbildung der Senkenfunktion durch die Verwendung standortspezifischer Simulationswerte des biophysikalischen EPIC-Modells erreicht. Zur Verschneidung der standortspezifischen EPIC-Werte mit dem regionsspezifischen Betriebsmodell der Studie, und auch um die mangelnde Anzahl an EPIC-Simulationen auszugleichen, wurden letztere verallgemeinert. Im Ergebnis, sind diese aber immer noch detaillierter und aussagekräftiger als die IPCC-Faktoren.

Aus der Auswahl landwirtschaftlicher Maßnahmen, welche die Boden-C Anreicherung fördern, nämlich konservierende Bodenbearbeitung, erhöhter Organikeintrag durch Ernteresteeinarbeitung und Fruchtfolgeanpassung, wurde zunächst ein Szenario erstellt in dem die konservierende Bodenbearbeitung forciert wird. Dieser Maßnahme wird international ein großes Potenzial zugesprochen. Es wurden Mindestanteile, welche die konservierende Bodenbearbeitung je Betrieb einnehmen musste, vorgegeben. Diese waren 40%, 70% und 100%. Im Ergebnis zeigte sich, dass sämtliche Betriebe in der EU-15 solche Vorgaben erfüllen könnten. Ab einem forcierten Mindestanteil von 80% treten im Durchschnitt aber wirtschaftliche Verluste ein. Ursache hierfür ist zuvorderst die Inkompatibilität einiger Fruchtfolgen mit der konservierenden Bodenbearbeitung, in erster Linie solche mit hohem Zuckerrübenanteil. Bei den analysierten Betrieben ist die Bandbreite an wirtschaftlichen Verlusten durch unterschiedliche Fruchtfolgen, standortspezifische Faktoren, und Betriebsstrukturen enorm groß. Im Vergleich zum Durchschnittsverlust von 20 €/ha bei auf 100% forcierter, konservierender Bodenbearbeitung erleiden einzelne Betriebe einen Verlust von bis zu 350 €/ha (Ackerbaubetrieb in Lüttich, Belgien).

Trotz des großen Potenzials, denn Böden speichern potenziell dreimal so viel Kohlenstoff wie die gesamte Vegetation und zweimal so viel wie die Atmosphäre enthält, wurde in diesem Szenario eine Anreicherung von maximal 32 kg C/ha erreicht. Für die EU-15 entspricht diese marginale Menge einer jährlichen Anreicherung von circa 1,0 Million Tonnen Boden-C bzw. 3,7 Millionen Tonnen CO_2. Ferner ist die Reversibilität der Anreicherung zu berücksichtigen. Vor dem Hintergrund geringer Anreicherung und teilweise extremer, wirtschaftlicher Verluste wird der Politik empfohlen von einer forcierten, konservierenden Bodenbearbeitung als Instrument des Klimaschutzes abzusehen.

In einem zweiten Szenario, welches aufgrund der niedrigen Kohlenstoffanreicherung des ersten Szenarios entstand, wurden Mindestanreicherungsraten vorgegeben. Den Betrieben stehen dabei neben der konservierenden Bodenbearbeitung sämtliche agrarischen Maßnahmen zur Verfügung, d.h. neben konservierender Bodenbearbeitung auch Anbau humusmehrender Kulturen oder Stroheinarbeitung. Untersucht wurden die ökonomischen Auswirkungen einer forcierten Anreicherung von 0,5 t C/ha und 1,0 t C/ha. Es zeigte sich, dass solche Raten nicht von allen Betrieben erreicht werden können. Dies trifft auf Betriebe in 17 bzw. 25 Regionen der über 100 untersuchten Regionen zu. Dennoch summiert sich die Anreicherung in den restlichen Regionen auf bis zu 181 Millionen Tonnen CO_2. Die Politik sollte aber auch von einer Regelung zur forcierten Mindestanreicherung absehen. Hauptargument ist das schwierige Monitoring einer Mindestanreicherung, denn standortspezifisch ist dieses zu aufwendig. Ferner haben Betriebsleiter aufgrund der multiplen Einflussfaktoren, die außerhalb deren Kontrolle liegen (z.B. Wetter), keine Erfolgsgarantie dafür, dass ergriffene Maßnahmen die gewünschte Anreicherung bewirken.

Die Vermeidungskosten liegen im Falle einer Mindestanreicherung von 1,0 t/ha im Durchschnitt bei 70 €/tCO_2. Wenn nur die Regionen betrachtet werden, in denen die Mindestanreicherung erzielt werden kann, so liegen diese bei nur 10 €/tCO_2. Dies ist ein konkurrenzfähiger Wert, bedenkt man, dass gegenwärtig EU-Emissionsberechtigungen für 20 €/tCO_2 gehandelt werden. Aufgrund des enormen Minderungspotenzials des Szenarios und der relativ geringen CO_2-Vermeidungskosten ist die Boden-C-Anreicherung über eine flexible Auswahl an agrarischen Maßnahmen also trotz des schwierigen Monitorings attraktiv. Bei der Entwicklung effektiver, politischer Werkzeuge sei auf die Methoden der Humusbilanzierung der Cross-Compliance-Regelung verwiesen. Die darin verwendeten Standardbilanzierungswerte könnten mittels EPIC-Werte zielgerichtet verbessert werden.

Neben den Szenarien zur Boden-C-Anreicherung wurde die Biogas-Produktion und –Verwertung in einem BHKW mit Stromeinspeisung als Produktionsalternative simuliert. In diesem dritten Szenario, wurden unterschiedliche Nutzungsraten für die aus dem BHKW anfallende Abwärme unterstellt (0 - 100%). Im Ergebnis zeigte sich, dass in der EU-15 die landwirtschaftliche Wertschöpfung um 1,6 bis 9,2 € Milliarden, je nach Wärmenutzungsrate, steigen könnte. Die Regelung der Cross-Compliance zur Einhaltung einer zumindest ausgeglichenen Humusbilanz begrenzt dabei höhere Einnahmen. Würde diese fallen, erhöhten sich die Einnahmen um eine weitere Milliarde Euro. Der Beitrag zum Klimaschutz summiert sich auf 47 bis 263 Millionen Tonnen CO_2 entsprechend der Wärmenutzungsrate. Im besten Fall könnten damit 60% der landwirtschaftlichen Emissionen ausgeglichen werden. Auf volkswirtschaftlicher Ebene, d.h. nach Abzug des in der Einspeisevergütung enthaltenen Subventionsanteils, ergibt sich ein Gewinn von 5 €/tCO_2 bei 100% Wärmenutzung und ein Verlust von 30 €/tCO_2 bei 0% Wärmenutzung.

Ein präsentes Thema in Zusammenhang mit der landwirtschaftlichen Biogasproduktion ist der Flächenverbrauch und damit die Nutzungskonkurrenz zur Nahrungsmittelerzeugung. Bei voller Ausschöpfung des Biogasproduktionspotenzials, d.h. bei 100% Abwärmenutzung, wären 28,7% des Grünlandes und 18,5% des Ackerlandes gebunden, obgleich eine wirtschaftsdüngerunabhängige Biogasproduktion im Modell nicht zugelassen wurde. Auswirkungen auf die Agrarpreise sind damit mehr als wahrscheinlich, können aber mittels des verwendeten Betriebsmodells nicht abgebildet werden. Hierfür bedürfte es eines Gleichgewichtmodells. Alternativ wurden in der Studie Quellen zitiert, welche Agrarpreisprognosen anhand verschiedener Entwicklungspfade unter Einbezug der Bioenergieerzeugung abgeben. In Hinblick auf politische Handlungsempfehlungen, kommt die Studie zu dem Schluss, dass sich die Subventionierung der Biogasproduktion auf die Verwendung von Wirtschaftsdüngern und Abwärme aus BHKWs konzentrieren sollte, um damit die Flächenkonkurrenz, wie sie beispielsweise durch einen Bonus auf nachwachsende Rohstoffe befeuert wird, zu entschärfen.

6.1.1.1 References

Amon, T.; and Döhler, H. (2006): Qualität und Verwertung des Gärrestes. In: Handreichung Biogasgewinnung und –nutzung, pp. 153 - 165. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow, 2006.

Angenendt, E.A. (2003): Entwicklung eines ökologisch-ökonomischen Modells für extensive Futterbaubetriebe zur Abbildung der Emissionen klimarelevanter Gase aus der Landwirtschaft und zur Bewertung von Minderungsstrategien. Agrarwirtschaft, Sonderheft 176.

Asman, W.A.H. (2001): Modelling the Atmospheric Transport and Deposition of Ammonia and Ammonium: An Overview with special Reference to Denmark. In: Atmospheric Environment 35, pp. 1969 - 1983.

Balkovic, J., E. Schmid, E. Moltchanova, R. Skalsky, K. Poltarska, B. Müller, and R. Bujnovsky (2007): Data processing for bio-physical process modelling in EU25. In: Stolbovoy V., L. Montanarella, and P. Panagos: Carbon Sink Enhancement in Soils of Europe: Data Modelling, Verification. JRC Scientific and Technical Reports. European Communities 2007, Luxembourg, pp. 74 - 139. ISBN 978-92-79-07691-6.

Bartens and Mosolff (2002): Zuckerwirtschaft Europa 2003. Verlag Dr. Albert Bartens, Berlin.

Baudoux, P. (2000): Beurteilung von Agrarumweltprogrammen am Beispiel von Baden-Württemberg und Brandenburg. Agrimedia Verlag, Bergen/Dumme.

Beese, F. (1994): Gasförmige Stickstoffverbindungen – Stickoxide und Distickstoffoxide. In: Enquete-Kommission „Schutz der Erdatmosphäre“ (1994): Dritter Bericht zum Schutz der Grünen Erde – Klimaschutz durch umweltgerechte Landwirtschaft und Erhalt der Wälder. Bundesdrucksache 12/8350, Bonn.

BiofuelsTP (2009): European Biofuels Technology Platform. Copyright owned by CPL Press 2009. Found at URL: http://www.biofuelstp.eu, in November 2009.

BMELF (2000a): Agenda 2000- Tierprämien. Bundesministerium für Ernährung, Landwirtschaft und Forsten, Bonn.

BMELF (2000b): Agenda 2000- Pflanzlicher Bereich Agrarumweltmaßnahmen. Bundesministerium für Ernährung, Landwirtschaft und Forsten, Bonn.

BMVEL (2005): Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten in der Bundesrepublik Deutschland 2005. Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, Berlin. Landwirtschaftsverlag GmbH, Münster-Hiltrup.

BMVEL (2006): Direktzahlungen – Verpflichtungenverordnung. Gesetz vom 21. Juli, 2004. Found at URL: http://www.bmelv.de/nn_751436/SharedDocs/Gesetzestexte/D/Direktzahlungen-Verpflichtungenverordnung.html__nnn=true, in October, 2006.

Bode, S. And Groscurth, H. (2006): Zur Wirkung des EEG auf den Strompreis. HWWA Discussion Paper 348. Found at URL: http://www.wind-energie.de/fileadmin/dokumente/Themen_A-Z/Kosten/HWWA_EEG_drueckt_Strompreis.pdf

Bouwman, A.F. (1994): Method to Estimate Direct Nitrous Oxide Emissions from Agricultural Soils. Report 773004004, p. 28. National Institute of Public Health and Environmental Protection, Bilthoven, Netherlands.

Boyle, M. (2001): Erosion's Contribution to Greenhouse Gases. Forester Communications, California, USA. Found at URL: http://www.forester.net/ecm_0201_gases.html, in May 2007.

Brand-Sassen (2004): Bodenschutz in der deutschen Landwirtschaft-Stand und Verbesserungsmöglichkeiten. Dissertation Georg-August-Universität Göttingen.

Brookes (2003): European Arable Crop Profit Margins. Ed. 1. Elham, Canterbury.

Bundesgesetzblatt (2006): Verordnung zur Änderung saatgutrechtlicher und düngemittelrechtlicher Vorschriften. Bundesgesetzblatt 2163, Jahrgang 2006, Teil I, Nr. 44, Bonn.

Campling, P.; Terres, J.M.; Vande Walle, S.; Van Orshoven, J.; and Crouzet, P. (2005): Estimation of Nitrogen Balances from Agriculture for EU-15: Spatialisation of Estimates for River Basin Using the CORINE Land Cover. In: Physics and Chemistry of the Earth, Vol. 30 (2005), pp. 25 - 34. Elsevier.

CAPRI (2006): Historic Yields in Europe. Personal Communication with Witzke, H.-P., University of Bonn, Germany.

CAPRI (2010): Supply Module. Found at URL: http://www.capri-model.org/dokuwiki/doku.php?id=cpari:concept:supply, in 2010.

Carter, T. and Hulme, M. (1999): Representing Uncertainty in Climate Change Scenarios and Impact Studies, ECLAT-2 Red Workshop Report, Climatic Research Unit, Norwich.

Council Regulation (1999): Council Regulation (EC) No 1254/1999 of 17 May 1999 on the common organisation of the market in beef and veal. Official Journal of the European Communities, L 160/21.

Council Regulation (2006): Council Regulation (EC) No 318/2006 of 20 February 2006 on the common organisation of the markets in the sugar sector. Official Journal of the European Union.

Davidson, D.A. (1999): Geleitwort zu R.P.C. Morgan: Bodenerosion und Bodenerhaltung. Thieme Verlag.

Dawen, Y.; Kanae, S.; Oki, T.; Koike, T.; and Musiake, K. (2003): Global Potential Soil Erosion with Reference to Land Use and Climate Changes. In: Hydrological Processes, Vol. 17, pp. 2913 - 2928. Wiley, Chichester, United Kingdom.

DBV, ADR, and WVZ, 2006: Reform der Zuckermarktordnung. Fragen und Antworten der Praxis. Deutscher Bauernverband, Arbeitsgemeinschaft Deutscher Rübenverbände, Wirtschaftliche Vereinigung Zucker e.V.

De Cara, S. and Jayet, P.A. (2000): Emissions of Greenhouse Gases from Agriculture: The Heterogeneity of Abatement Costs in France. European Review of Agricultural Economics, Vol. 27(3), pp. 281 - 303.

De Cara, S. And Jayet, P.A. (2009): Marginal Abatement Costs of Greenhouse Gas Emissions from EU-24 Agriculture. Greenhouse Gas Emission Abatement Workshop, Dublin (Ireland). April, 2nd, 2009.

DEFRA (2002): Stabilisation and Commitment to Future Climate Change. Scientific Results from the Hadley Centre. Department for Environment, Food and Rural Affairs, DEFRA. Hadley Centre, Berkshire, United Kingdom.

Directive 2001/77/EC: Directive on Electricity Production from Renewable Energy Sources. European Commission, Brussels.

Directive 2003/30/EC: Directive on the Promotion of the Use of Biofuels or other Renewable Fuels for Transport. European Commission, Brussels.

DG AGRI (2007): Sugar and Isoglucose Production by Quota. Directorate General for Agriculture. European Commission. Found at URL: http://europa.eu.int/comm/agriculture/agrista/2004/table_en/4361.pdf, in January, 2007.

DG Energy and Transport (2009): EU energy and transport in figures. Statistical Pocket Book 2009. Directorate General for Energy and Transport. European Commission. ISSN 1725-1095.

DNDC (2006): De-Nitrification De-Composition. Version 8.9. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, USA.

Döhler, H.; Eurich-Menden, B.; Hartung, E. (2004): Gute fachliche Praxis der Ammoniak-Emissionsminderung in der Tier- und Pflanzenproduktion. AID-KTBL Broschüre, Darmstadt.

Döhler, H. (2006): Verfügbare und zukünftige Technologien in den Bereichen Wärme, Strom und Treibstoffe. Vortragsreihe, Landwirtschaftlicher Hochschultag 2006. Landinfo 5/06.

Duchateau, K. and Vidal, C. (2003): Verringerung der Treibhausgasemissionen der europäischen Landwirtschaft um 6,4% (1990-2000). Statistik kurz gefasst, Umwelt und Energie, Thema 8-1/2003, EUROSTAT.

DWD (2003): Deutscher Wetterdienst. Die Phänologie im DWD. DWD, Offenbach.

EFMA (2005): European Fertilizer Manufacturers Association, Brussels, Belgium. Found at URL: http://www.efma.org/statistics/section23.asp, in May, 2005.

Elsbett Technologie GmbH (2007): Elsbett-Pionier der Pflanzenöltechnologie. Found at URL: http://www.elsbett.com, in September, 2007.

Enguídanos, M.; Soria, A.; Kavalov, B. and Jensen, P. (2002): Techno-economic analysis of Bio-diesel production in the EU: a short summary for decision makers. European Commission, Joint Research Centre. Report EUR 20279 EN.

EPIC (2006): Environmental Policy Integrated Climate. Williams, J. and Meinardus, A., Texas A&M University, USA.

Europäische Kommission (2005): Der Europäische Zuckersektor – Seine Bedeutung und Zukunft. Europäische Kommission, Brüssel.

European Commission (1997): CAP 2000-Situation and Outlook. Cereals, Oilseeds and Protein Crops. Working Document. Directorate General for Agriculture.

European Commission (2004): The share of renewable energy in the EU. Country Profiles. Overview of Renewable Energy Sources in the Enlarged European Union. {COM(2004)366 final}.

European Commission (2005): Biomass Action Plan. European Commission, Brussels. SEC(2005), 1573.

European Commission (2006): CAP Reform. Found at URL: http://ec.europa.eu/agriculture/capreform/index_en.htm, in November, 2006.

European Commission (2007a): CAP reform – a long-term perspective for sustainable agriculture. Found at URL: http://europa.eu.int/comm/agriculture/capreform/index_en.htm, in January, 2007.

European Commission (2007b): Overview of the implementation of the CAP reform (first and second wave of the reform). Found at URL: http://ec.europa.eu/agriculture/markets/sfp/ms_en.pdf, in January, 2007.

European Commission (2007c): Financial Programming and Budget. EU Budget at a glance. Found at URL: http://ec.europa.eu/budget/budget_glance/what_for_en.htm, in May, 2007.

European Commission (2007d): Renewable Energy Road Map. Renewable Energies in the 21st Century: Building a more Sustainable Future. COM(2006) 848 final. Brussels, 10.01.2007.

European Commission (2009): Agriculture and Bioenergy. Found at URL: http://ec.europa.eu/agriculture/bioenergy/index_en.htm

EUROSTAT (1996): Farm Structural Survey 1996. Statistical Office of the European Communities, Unit E2, Agriculture Statistics, Production, Luxembourg.

EUROSTAT (2003): Struktur und Typologie der Landwirtschaftlichen Betriebe. Dok. CLASSEX 322. Europäische Kommission, Direktion F, Luxemburg.

EUROSTAT (2005): Online Database on Agriculture and Forestry. Purchase Prices of the Means of Agricultural Production (absolute annual prices). Diesel prices. Found at URL: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL, in May, 2005.

EUROSTAT (2007): Online Database on Agriculture and Forestry. Yield of Cereals excluding Rice. Found at URL: http://epp.eurostat.ec.europa.eu, in December, 2007.

EUROSTAT (2007b): Online Database on Agriculture and Forestry. Purchase Prices of the Means of Agricultural Production (absolute annual prices). Diesel prices. Found at URL: http://epp.eurostat.ec.europa.eu, in December, 2007.FADN (2006): Farm Accountancy Data Network, Methodology. Found at URL: http://ec.europa.eu/agriculture/rica/methodology_en.cfm, in July, 2006.

Ferrero, Aldo (2006): Rice Cultivation in the EU-15. Dipartimento di Agronomia, Selvicoltura e Gestione del Territorio, Università di Torino. Personal Communication on December 1, 2006.

Fachverband Biogas e.V. (2007): Biogas 2006: Zubau erstmals gleichauf mit Windkraft. Pressemitteilung. Leipzig, 1. Februar, 2007. Fachverband Biogas e.V., Freising.

Fachverband Biogas e.V. (2010): Biogas: Eine Chance für die Landwirtschaft! Fachverband Biogas, Freising.

FNR (2005): Ergebnisse des Biogasmessprogramms. Fachagentur für Nachwachsende Rohstoffe e.V., Gülzow.

FNR (2006): Bedeutung des Erneuerbare-Energien-Gesetzes. Fachagentur für Nachwachsende Rohstoffe e.V., Gülzow.

FNR (2007): Biogasnutzung in Deutschland- Entwicklung 1992 - 2007. Fachagentur für Nachwachsende Rohstoffe e.V., Gülzow. Stand 09/2007. Found at URL: http://www.fnr.de, in August, 2009.

FNR (2008): Biogas- Basisdaten Deutschland. Stand: Oktober 2008. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz und Fachagentur für Nachwachsende Rohstoffe.

Forschungszentrum Karlsruhe (2002): Gelbes Stroh statt Schwarzes Gold. Presseinformation 20/2002. Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft.

Freibauer, A. and Kaltschmitt, M. (2001): Biogenic Greenhouse Gas Emissions from Agriculture in Europe. European Summary Report. Vol. 78. IER, Stuttgart.

Fuchs, M., Baritz, R.; Adler, G.H. and Schulzke, D. (2005): Derivation of spatially explicit rotation-like combinations of crops as data input for agro-economical simulation models. INSEA-Report.

Gallmann, E. (2003): Vergleich von zwei Haltungssystemen für Mastschweine mit unterschiedlichen Lüftungsprinzipien- Stallklima und Emissionen. Dissertation, Universität Hohenheim. VDI MEG 404.

Gay, S.H.; Osterburg, B.; Baldock, D. and Zdanowicz, A. (2005): Recent evolution of the EU Common Agricultural Policy (CAP): state of play and environmental potential. MEACAP, Sixth Framework Programme, European Commission.

Gibbs, M.J. and Leng, R.A. (1993): Methane emissions from livestock. In: Methane and Nitrous Oxide [van Amstel, A.R. (ed.)]. RVM Report No. 481507003. National Institute of Public Health and Environmental Protection. Bilthoven, Netherlands. pp. 73 – 79.

Goebbel, T. (2006): Erfolgreich auch ohne Prämien. DLZ, 2006, 10. Ausgabe.

Henniges, O. (2006): Die Bioethanolproduktion – Wettbewerbsfähigkeit in Deutschland unter Berücksichtigung der internationalen Konkurrenz. EUL Verlag, Köln.

Hoffmann, H and Hege, U. (1991): Gülle - ein wertvoller Wirtschaftsdünger. Bachem, Köln.

Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J.; Dai, X.; Maskell, K. and Johnson, C.A. (2001): Climate Change 2001: The Scientific Basis. Intergovernmental Panel on Climate Change (IPCC).

IIASA (2007): Integrated Sink Enhancement Assessment (INSEA). International Institute of Applied Systems Analysis, Laxenburg (Austria). Found at URL: http://www.iiasa.ac.at/Research/FOR/INSEA/index.html, in April, 2007.

IPCC (1997a): Greenhouse Gas Inventory: Reference Manual. Edited by: Houghton, J.T.; Meira Filho, L.G.; Lim, B.; Tréanton, K.; Mamaty, I.; Bonduki, Y.; Griggs, D.J. and Callander, B.A. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 3.

IPCC (1997b): Greenhouse Gas Inventory: Workbook. Edited by: Houghton, J.T.; Meira Filho, L.G.; Lim, B.; Tréanton, K.; Mamaty, I.; Bonduki, Y.; Griggs, D.J. and Callander, B.A. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 2.

IPCC (2001): Climate Change 2001. Working Group 1: The Scientific Basis. Found at URL: http://www.grida.no/climate/ipcc_tar/wg1/040.htm, in August, 2006.

IPCC (2006a): About IPCC. Mandate. Found at URL: http://www.ipcc.ch, in September, 2007.

IPCC (2006b): 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miw, K., Ngara, T., and Tanabe, K. (eds.). Published by IGES, Japan.

IPCC (2006c): 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2: Energy. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miw, K., Ngara, T., and Tanabe, K. (eds.). Published by IGES, Japan.

IUC (1999): Informationsblätter zum Klimawandel. Informationsstelle für Übereinkommen (IUC), UNEP, Châtelaine, Schweiz.

Izaurralde, R.C.; Williams, J.R.; McGill W.B.; Rosenberg, N.J. and Quiroga, M.C. (2006): Simulating soil C dynamics with EPIC: Model description and testing against long-term data. In: Ecological Modelling 192 (3 - 4), pp. 362 - 384.

Jäger, P.; Schwab, M.; and Stephany, R. (2006): Betriebsform, Arbeitszeit, Steuern. In: Handreichung Biogasgewinnung und –nutzung, pp. 166 - 181. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow.

Jäkel, K. and Böhlitz-Ehrenberg (2000): Grundlagen der Biogasproduktion. Bauen für die Landwirtschaft, Themenheft Biogas. 3. Ausgabe, pp. 3 - 7.

Jones, C.A.; Eve, M.; House, R.; Lewandrowski, J.; Paustian, K.; Peters, M. and Sperow, M. (2001): Economics of Sequestering Carbon in the U.S. Agricultural Sector. Technical Bulletin, Number 1909. United States Department of Agriculture.

Kaltschmitt, M. and Reinhardt, G.A.(1997): Nachwachsende Energieträger in Deutschland. Potentiale und Kosten. Springer-Verlag, Berlin.

Kazenwadel, G. (1999): Ökonomisch/ökologische Beurteilung von Agrar- und Umweltprogrammen in der Europäischen Union. Agrarwirtschaft, Sonderheft 162.

Kiehl, J.T. and Trenberth, K.E. (1997): Earth’s Annual Global Mean Energy Budget. Bulletin American Meteorological Society, 78. pp. 197 - 208.

Kirchgessner, M., Windisch, W. and Müller, H.L. (1994): Methane Release from Dairy Cows and Pigs. In: European Association for Animal Production, Vol. 76.

Kirchgessner, M. (1997): Tierernährung - Leitfaden für Studium, Beratung und Praxis. 10. Ausgabe. DLG-Verlags-GmbH, Frankfurt a.M.

Kleffmann (2005): Kartoffel-Panel 2004. Found at URL: http://www.kleffmann.com/Study_05_2005_DE.html, in September, 2005.

Kleinhanss, W., Bertelsmeier, M. and Offermann, F. (2003): Aufbau und Anwendung des FAL-Modellverbundes für die Politikberatung. Agrarwirtschaft 52, Heft 4.

Klimont, Z. and Brink, C. (2004): Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. Interim Report IR-04-048, Transboundary Air Pollution Program. IIASA, Austria.

Klinski, S. (2006): Einspeisung von Biogas in das Erdgasnetz. Hrsg.: Fachagentur Nachwachsende Rohstoffe e.V., Gülzow. 2. Auflage.

KTBL (2000): Taschenbuch Landwirtschaft 2000/01. Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt.

KTBL (2003): Taschenbuch Betriebsplanung 2002/03. Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt.

KTBL (2004): Taschenbuch Betriebsplanung 2004/05. Kuratorium für Technik und Bauswesen in der Landwirtschaft, Darmstadt.

Krayl, E. (1993): Strategien zur Verminderung der Stickstoffverluste aus der Landwirtschaft. Wissenschaftsverlag Vauk, Kiel.

Kriegl, W.; Schneeberger, W.; and Walla, C. (2005): Strom oder Kraftstoff aus Biogas – ein ökonomischer Vergleich. BOKU, Wien.

Kyoto Protocol (2005a): Kyoto Protocol to the United Nations Framework on Climate Change. Annex B, National Commitments. Found at: URL: http://unfccc.int/essential_background/kyoto_protocol/items/2830.php, in September, 2006.

Kyoto Protocol (2005b): Kyoto Protocol to the United Nations Framework on Climate Change. Background. Found at: URL: http://unfccc.int/essential_background/kyoto_protocol/items/3145.php, in September, 2006.

Lal, R.; Kimble, J.M.; Follett, R.F. and Cole, C.V. (1999): The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers.

Lal, R: (2001): Soil Carbon Sequestration and the Greenhouse Effect. Soil Science Society of America, Vol. 57.

Langbehn, L. (2007) BtL-Euphorie lässt nach. In DLG-Mitteilungen 5/2007.

Lauer, W. and Bendix, J. (1995): Klimatologie – Das Geographische Seminar. Verlag Westermann.

Lee, H.C. and McCarl, B. (2003): The Dynamic Competitiveness of U.S. Agricultural and Forest Carbon Sequestration. Canadian Journal of Agricultural Economics 53, pp. 343 - 357.

Leible, L., Kälber, S., Kappeler, G., Lange, S., Nieke, E., Proplesch, P., Wintzer, D., Fürniß, B. (2007): Kraftstoff, Strom und Wärme aus Stroh und Waldrestholz-eine systemanalytische Untersuchung. Wissenschaftliche Berichte, Forschungszentrum Karlsruhe.

Li, C., Narayanan, V.; and Harris, R. (1996): Model estimates of nitrous oxide emissions from agricultural lands in the United States. Global Biogeochemistry Cycles, Vol. 10, pp. 297 - 306.

LfL Bayern (2003): Ökonomik im Pflanzenbau. Bayerische Landesanstalt für Landwirtschaft. Found at URL: http://www.lfl.bayern.de/internet/stmlf/lfl/ilb/db/14249/index.php?context=/lfl/ilb/pflanze/, in December, 2005.

LfL Bayern (2006): Gruber Tabelle zur Fütterung der Milchkühe, Zuchtrinder, Mastrinder, Schafe und Ziegen. 27. Ausgabe. Bayerische Landesanstalt für Landwirtschaft.

LfL Sachsen (2008): Energetische Verwertung von Biomasse zu Biogas. Sächsische Landesanstalt für Landwirtschaft, LfL. 19 pages. Found at URL: http://landwirtschaft.sachsen.de, in July, 2008.

Loehte, K. (1999): Strategien zur Verminderung von Gasemissionen aus verschiedenen landwirtschaftlichen Betriebssystemen. Wissenschaftsverlag Vauk, Kiel.

Matthias, J., Jäger, P., Klages, S., and Niebaum, A. (2006): Rechtliche und administrative Rahmenbedingungen. In: Handreichung Biogasgewinnung und –nutzung, pp. 137 - 152. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow, 2006.

McCarl, B.A. and Spreen, T.H. (2004): Applied Mathematical Programming Using Algebraic Systems. Found at URL: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/books.htm, in November, 2007.

Menzi, H., Frick, R. and Kaufmann, R. (1997): Ammoniakemissionen in der Schweiz: Ausmaß und technische Beurteilung des Reduktionspotenzials. Schriftenreihe der FAL Nr. 26, Zürich-Reckenhorst.

MLR (2005): Düngung von Wiesen und Weiden. Staatliche Lehr- und Versuchsanstalt für Viehhaltung und Grünlandwirtschaft, Baden-Württemberg. 13. Ausgabe.

Montgomery, M. and Larsen, O.H. (2002): Field Test Corrosion Experiments in Denmark with Biomass Fuels. Part 2: Co-Firing of Straw and Coal. In: Materials and Corrosion, Vol. 53, Issue 3, pp. 185 - 194. WILEY-VCH Verlag GmbH & CO KGaA, Weinheim.

Neufeldt, H. (2005): Carbon stocks and sequestration potentials of agricultural soils in the federal state of Baden-Württemberg, SW Germany. Journal of Plant Nutrition and Soil Science, 168. pp. 202 – 211.

Niebaum, A. and Döhler, H. (2006): Modellanlagen. In: Handreichung Biogasgewinnung und –nutzung, pp. 117 - 136. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow.

Obersteiner, M. (2003): Annex I - Description of Work. Contract Number 503614 (INSEA).

Österreichische Hagelversicherung (2007): Klima Daten – Europa. Österreichische Hagelversicherung VVaG, Wien. Found at URL: http://www.hagel.at, in July, 2007.

PELCOM (1996): Project work programme for a shared cost action under Environment and Climate of the EU 4th framework RTD&D programme (17-05-1996). PELCOM, Wageningen, Netherlands.

PELCOM (2006): Pelcom 1km pan-European Land Cover Database. Prepared by C.A. Mücher. PELCOM, Centre for Geo-Information, Wageningen, Netherlands. Found at: http://www.geo-informatie.nl/projects/pelcom/public/index.htm, in October, 2006.

Pérez Domínguez, I. (2006): Greenhouse Gases: Inventories, Abatement Costs and Markets for Emission Permits in European Agriculture. European University Studies, Series V, Vol. 3184. Peter Lang, Frankfurt a.M.

Pölzl, W. and Salchenegger, S. (2005): Biogas im Verkehrssektor. Technische Möglichkeiten, Potenzial und Klimarelevanz. Umweltbundesamt, Wien.

Pries, M. and Menke, A. (2005): Futterwerttabellen für Schafe mit Bedarfsnormen und Vorgaben zur Fütterung. Published in May, 2005. Found at URL: http://www.landwirtschaftskammer.de/fachangebot/tierproduktion/schafhaltung/fuetterung/futterwerte-schafe.htm, in October, 2006.

Rasmussen, P.E.; Goulding, K.W.T.; Brown, J.R.; Grace, P.R.; Janzen, H.H.; and Körschens, M. (1998): Long-term agroecosystems experiments: assessing agricultural sustainability and global change. Science, Vol. 282, pp. 893 - 896.

Reisch, E. and Zeddies, J. (1992): Einführung in die landwirtschaftliche Betriebslehre. Band 2: Spezieller Teil. 3. Auflage. Ulmer, Stuttgart.

Roadmap Biokraftstoffe (2007): Roadmap Biokraftstoffe. Gemeinsame Strategie von BMU/BMELV, VDA, MWV, IG, VDB und DBV.

Ruppert, W.; Stichelmaier, M.; Bauchhenss, J.; Blendl, H.M.; Haisch, A.; Hammer, K.; Hege, U.; Juli, R.; Melian, L.; Nürnberger, W.; Rieder, J.; Rintelen, P.; Rutzmoser, K.; Weber, W.; Wurzinger, A. and Zeisig, H. (1985): Daten und Information zum Gülleeinsatz in der Landwirtschaft. Bayerisches Landwirtschaftliches Jahrbuch, 8. Ausgabe, pp. 899 - 996.

Schäfer, M.; Angenendt, E.; Neufeldt, H.; and Zeddies, J. (2003): Modellierung klimarelevanter Emissionen aus der Landwirtschaft Baden-Württembergs. Perspektiven in der Landnutzung- Regionen Landschaften, Betriebe – Entscheidungsträger und Instrumente. Schriften der Gesellschaft für Sozialwissenschaften des Landbaues e.V. Ausgabe 38. Münster-Hiltrup.

Schäfer, M. (2006): Abschätzung der Emissionen klimarelevanter Gase aus der Landwirtschaft Baden-Württembergs und Bewertung von Minderungsstrategien unter Nutzung eines ökonomisch-ökologischen Regionalmodells. Dissertation.

Schattauer, A. and Weiland, P. (2006): Grundlagen der anaeroben Fermentation. In: Handreichung Biogasgewinnung und –nutzung, pp. 25 - 35. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow.

Schmid, E.; Balkovic, J.; Bujnovsky, R.; Poltarska, K.; Skalsky, R. and Stolbovoi, V. (2004): Report on Database Strategy. Biophysical Process Modelling for EU-25: Concept, Data and Methods. INSEA Report D7.

Schmid, E.; Balkovic, J.; Blank, D.; De Cara, S.; Obersteiner, M.; Schneider, U.A. and Skalsky, R. (2005): Environmental and Economic Impact Analysis of Alternative Management Practices in Baden-Württemberg. INSEA Report.

Schmid, E.; Balkovic, J.; Moltchanova, E.; Skalsky, R.; Poltarska, K.; Müller, B.; and Bujnovsky (2006a): Biophysical Process Modelling for EU-25: Concept, Data, and Results. Final Research Report for the Integrated Sink Enhancement Assessment (INSEA) project. International Institute of Applied Systems Analysis (IIASA), Laxenburg (Austria).

Schmid, E. (2007): Data Exchange within INSEA-Project. Data extracts from EPIC-Model.

Schmitz, P.M.; Zeddies, J.; Arnold, K.; and Vetter, A. (2009): Potenziale der Bioenergie- Chancen und Risiken für landwirtschaftliche Unternehmen. Arbeiten der DLG Band 204. Studie im Auftrag des DLG-Strategierates. DLG-Verlags-GmbH, Frankfurt a.M. (Germany).

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

Schneider, U.A.; Schmid, E.; Blank, D.; Kraxner, F. (2004): Agricultural Data Base Strategy for INSEA. INSEA Report D7.

Schnellnhuber, H.J. (2006): Die unsicherste Variable ist der Mensch. Interview by J. Rubner. Published in Süddeutsche Zeitung, on October 19, 2006.

Schöpe, M. and Britschkat, G. (2002): Gesamtwirtschaftliche Bewertung des Rapsanbaus zur Dieselproduktion in Deutschland. Sonderdruck aus ifo-Schnelldienst Nr. 6. IFO, München.

Scholwin, F.; Weidele, H. and Gattermann, H. (2006): Gasaufbereitung und Verwertungsmöglichkeiten. In: Handreichung Biogasgewinnung und –nutzung, pp. 97 - 116. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow.

Statistisches Jahrbuch (2005): Statisches Jahrbuch über Ernährung, Landwirtschaft und Forsten. Eds.: Bundesministerium für Ernährung, Landwirtschaft und Forsten, Berlin. Landwirtschaftsverlag, Münster.

Steinhauser, H.; Langbehn, C.; and Peters, U. (1992): Einführung in die landwirtschaftliche Betriebslehre. Allgemeiner Teil. Band 1. 5. Auflage. Ulmer, Stuttgart.

Stern, N. (2006): Stern Review on the Economics of Climate Change. HM Treasury, United Kingdom. Found at URL: http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm , in June, 2007.

Stolk, van, C.; Tiessen, J.; Schoeler, van, C.; and Wegrich, K. (2006): German Introduction of Single Farm Payments. RAND Corporation, RAND Europe, Cambridge, United Kingdom.

Thaer, A.D. (1809):Grundsätze der rationellen Landwirtschaft. Band 1. Berlin.

Thaer, A.D. (1821): Die Lehre von der Düngung. Reprint of the original version from 1821 (Grundsätze der rationellen Landwirtschaft). Landwirtschaftsausstellung der DDR, Markkleeberg.

Thünen, J.H., von (1826): Der isolierte Staat in Beziehung auf Landwirthschaft und Nationalökonomie. Perthes, Hamburg.

Thünen, J.H. von (1966): Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie. Stuttgart, Reprint 4.

Top Agrar (2002): Top Agrar Fachbuch: Biogas- Strom aus Gülle und Biomasse. Landwirtschaftsverlag, Münster.

Triebe, S. (2007): Reduktion von Treibhausgasemissionen aus der Landwirtschaft – Dargestellt für die Bundesländer Brandenburg und Niedersachsen. Josef Eul Verlag GmbH, Lohmar, Köln.

UBA (1994): Enquete Kommission “Schutz der Erdatmosphäre”; Dritter Bericht zum Thema Schutz der grünen Erde – Klimaschutz durch umweltgerechte Landwirtschaft und Erhalt der Wälder, Bundesdrucksache 12/8350, Bonn.

UBA (2002): BMVEL/UBA-Ammoniak-Emissionsinventar der deutschen Landwirtschaft und Minderungsszenarien bis zum Jahre 2010. Forschungsbericht 29942245/02, UBA-FB 000249. Umweltbundesamt, Berlin.

UBA (2006): Globaler Klimawandel, Klimaschutz 2004. Found at URL: http://www.umweltdaten.de/publikationen/fpdf-l/2695.pdf, in August, 2006.

UFOP (2001): Biodiesel - Energie- und Umweltbilanz Rapsmethylester. Union zur Förderung von Öl- und Proteinpflanzen, Berlin.

UFOP (2007): Die aktuelle Biokraftstoff-Gesetzgebung. Union zur Förderung von Öl- und Proteinpflanzen, Berlin.

United Nations (2004): Strategies and Policies for Air Pollution Abatement. 2002 Review Prepared Under the Convention on Long-Range Transboundary Air Pollution. United Nations Publication, Geneva (Switzerland).

UNECE (2006): United Nations Economic Commission for Europe. Convention on Long-Range Transboundary Air Pollution. Found at URL: http://www.unece.org/env/lrtap, in September, 2006.

UNFCCC (1992): United Nations Framework Convention on Climate Change, Article 1. United Nations. FCCC/INFORMAL/84. Article retrieved from URL: http://unfccc.int/resource/docs/convkp/conveng.pdf, in April, 2007.

UNFCCC (2005): National Inventory Submission 2005. Found at URL: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/2761.php, in December, 2005.

UNFCCC (2008a): A Summary of the Kyoto Protocol. Found at URL: http://unfccc.int/kyoto_protocol/background/items/2879.php, in April, 2008.

UNFCCC (2008b): Land Use, Land-Use Change and Forestry. Background. Found at URL: http://unfccc.int/methods_and_science/lulucf/items/1084.php, in June, 2008.

UNFCCC (2009): Definition of Renewable Biomass. Annex 18, 23rd Meeting of the Executive Board, February 22-24, 2006. Found at URL: http://cdm.unfccc.int, in January, 2009.

Utesch, B. (2007): Chance nur für Großanlagen. In: DLG-Mitteilungen 10/2007. pp. 40 - 43.

VDN (2003): Auslegung des Gesetzes für den Vorrang von erneuerbaren Energien vom 29.03.2000. Verband der Netzbetreiber, e.V. Stand 1. Januar, 2003.

vTI (2008): Klima- und energiepolitische Analyse ausgewählter Bioenergie-Linien. Landbauforschung. Sonderheft 168. Johann Heinrich von Thünen-Institut (vTI). Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei, Braunschweig. ISSN 0376-0723.

Wagner-Riddle, C. (2004): Improved Greenhouse Gas Emission Estimates from Manure Storage Systems. Climate Change Funding Initiative in Agriculture, Final Project Report.

Wander, M. and Nissen, T. (2003): Value of Soil Organic Carbon in Agricultural Lands. In: Mitigation and Adaptation Strategies for Global Change, Volume 9: pp. 417 - 431. Kluwer Academic Publishers.

Wander, M. and Nissen, T. (2004): Value of Soil Carbon in Agricultural Lands. In: Mitigation and Adaptation Strategies for Global Change, 9. pp. 417 - 431. Kluwer Academic Publishers, Netherlands.

Werner, C. (2004): Erstellung eines N-Spurengas-Emissionskatasters für land- und forstwirtschaftlich genutzte Böden der Bundesrepublik Deutschland. Diplomarbeit.

West, T.O. and Post, W.M. (2002): Soil Carbon Sequestration by Tillage and Crop Rotation: A Global Data Analysis. Soil Science Society of America Journal (66).

WMO (2007): Frequently Asked Questions. World Meteorological Organization. Found at URL: http://www.wmo.ch/web/wcp/ccl/faq/faq.htm#q1, in April 2007.

Wood, S. and Cowie, A. (2004): A Review of Greenhouse Gas Emission Factors for Fertiliser Production. For IEA, Bioenergy, Task 38.

Zeddies, J. (2006a): Biokraftstoffquoten- Gibt es überhaupt genug Rohstoffe? Agrarwirtschaft 55.

Zeddies, J. (2006b): Potenziale für Bioenergie der deutschen und europäischen Landwirtschaft. Vortragsreihe, Landwirtschaftlicher Hochschultag 2006, Universität Hohenheim.

ZMP (2005): ZMP-Marktbilanz - Vieh und Fleisch 2005. Zentrale Markt- und Preisberichtstelle GmbH, Bonn.

ZMP (2004a): ZMP-Marktbilanz – Milch 2004. Zentrale Markt- und Preisberichtstelle GmbH, Bonn.

ZMP (2004b): ZMP- Marktbilanz – Getreide, Ölsaaten, Futtermittel. Zentrale Markt- und Preisberichtstelle GmbH, Bonn.

Zybell, G. and Wagner, E. (2006): Wie setzen sich Strompreise zusammen (Stand 2006)? Found at URL: http://www.energie-fakten.de/pdf/strompreise-2006.pdf

Annex 1 Phosphate and Potash Withdrawal by Plants (in kg/dt)

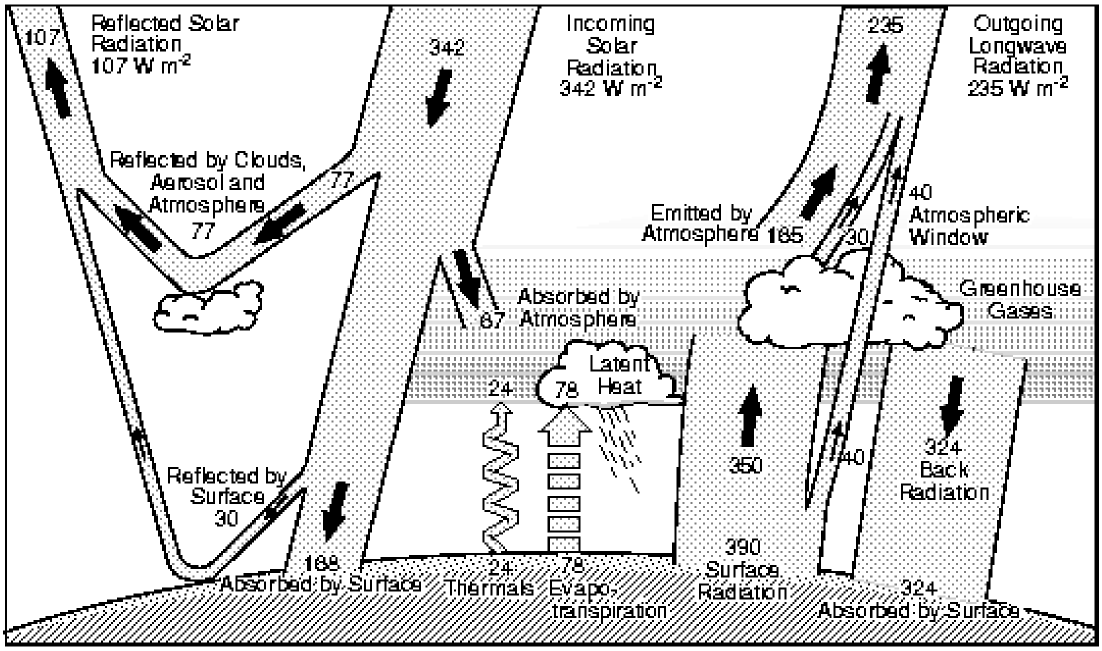
	Phosphate		Potash			Phosphate		Potash	
Crop	**Grain**	**Other**	**Grain**	**Other**	**Crop**	**Grain**	**Other**	**Grain**	**Other**
Wheat	0.90	0.30	0.60	1.80	Rapeseed	1.80	0.30	1.00	2.50
Winter Barley	0.90	0.30	0.60	1.80	Sunflower	1.50	0.20	2.30	2.10
Barley	0.90	0.30	0.60	1.80	Sugar beet	0.10	0.10	0.25	0.55
Oats	0.90	0.30	0.60	1.80	Potato	0.14	0.15	0.60	0.60
Rye	0.90	0.30	0.60	1.80	Silage Maize	0.20	0.20	0.43	0.43
Grain Maize	0.90	0.60	0.50	2.00	Clover	0.15	0.15	0.60	0.60
Soy bean	1.40	1.40	1.70	1.70	Catch crop	0.15	0.15	0.60	0.60

Annex 2 European Size Units (ESU) in the FADN

Country	**ESU***	**Country**	**ESU***	**Country**	**ESU***
Austria	8	Germany	8	Netherlands	16
Belgium	16	Greece	2	Portugal	2
Denmark	8	Ireland	2	Spain	2
Finland	8	Italy	4	Sweden	8
France	8	Luxembourg	8	UK	16

** In 2000 1 ESU corresponded to a gross margin of 1200 EUR*
Source: FADN, 2006.

Annex 3 Earth's Annual Global Energy Budget



Annex 4 FADN Clustering Schemes for Member States

Member State	Types of Farming	Economic Size Classes
BE	10, (2011+2012+2013+2030), (2021+2022+2023), 30, 411, 412, (42+44), 43, 501, (502+503), (60+811+812), 71, (72+82), (813+814)	6, 7, 8, 9
DK	13, 14, (2012+2022+2032), (2011+2021+2031+2013+2023+2033), 2034, 31, 32,33, 34, 41, (42+43+44), 50, (601+602+603+604+606), 605, 71, 72, 81, 82	(3+4), (5+6), 7, 8, 9, 10
DE	10, 20, 31, (32+33+34), 41, (42+43+44), 50, 60, 70, 80	(5+6), 7, 8, 9
EL	13, 14, 20, 31, 32, 33, 34, 40, 50, 60, 70, 81, 82	2, 3, 4, 5, 6, 7, (8+9)
ES	13, 14, 20, 31, 32, 33, 34, 41, 42, 43, 44, 50, 60, (70+80)	2, 3, 4, 5, 6, 7, 8, 9
FR	13, 14, (201+203), 202, 311, (312+313+314), (32+33+34), 41, (42+43), 44, 50, 60, 70, (811+813), (812+814), 82	(5+6), 7, 8, 9
IR	(10+60), 20, 30, (41+43+711), (42+444+712), (441+442+443), (50+72+821), (811+812), (813+814+822+823)	2, 3, 4, 5, 6, 7, 8, 9
IT	13, 14, (2011+2021+2030), (2012+2013+2022+2023), 31, 32, 33, 34, 411, 412, (42+43), 44, 50, 60, (70+82), 81	2, 3, 4, 5, 6, 7, 8, 9
LU	(10+60), 20, 30, 411, 412, (42+43+44), 50, (70+80)	5, 6, 7, (8+ 9)
NL	10, (2011+2031), 2021, (2012+2032), 2022, (2013+2023+2034), 2033, 31, 32, 33, 34, 411, 412, (42+43), 44, 5011, (5012+5013), 5021, (5022+5023+5030), 60, (71+72), 80	7, 8, 9
AT	13, 14, 20, 31, (32+34), 33, 41, 42, 43, 44, 50, 60, 71, 72, 81, 82	no aggregation
PT	(13+141+142+143+1441+1442), (1443+602+603+604+605+6062), (2011+2021+2031+601+6061), (2012+2022+2032+2013+2023+2033+2034), 31, 32, (33+34),	(1+2), 3, 4, 5, 6, 7, 8, 9

	41, (42+43), 44, 50, 70, 80	
FI	13, (14+602+605), (20+30+601+606), 603, 604, (41+711), (42+43+44+712), (50+72+82), 81	Regional different aggregation
SE	13, (14+60), 20, 30, 41, (42+43+44), 501, 502, 503, (70+80)	(5+6), 7, 8, 9

Source: FADN; NOTA BENE: There is no aggregation over regions in any country, except in Sweden.

Annex 5 Animal Premiums AGENDA 2000 Base

Animal Category	**2000**	**2001**	**2002**
		(€/head)	
Ewe and goat	16.80	16.80	16.80
Calves	17.00	33.00	50.00
Adult slaughter animals	27.00	53.00	80.00
Bulls	165.00	185.00	210.00
Suckler cow	244.00	272.00	300.00
Breeder suckler cow	213.00	232.00	250.00

Source: Council Regulation (1999)

Annex 6 Nutrient Contents in Manure in EU_EFEM

Animal Type	**Manure**	**P**	**K**	**Mg**	**Ca**
		(kg/m^3 for liquid) (kg/dt for solid)			
Cattle:					
dairy	liquid	2.0	5.8	0.9	2.0
fattening	liquid	2.3	4.5	0.9	2.0
breeding	liquid	1.9	6.0	0.9	1.9
Pigs:					
sows	liquid	3.3	3.3	1.0	3.0
fattening	liquid	2.8	3.1	1.0	3.0
breeding	liquid	3.3	3.3	1.0	3.0
Poultry:					
fattening	solid	7.5	6.1	1.0	3.0
breeding	liquid	2.8	3.0	0.8	0.0
Others:					
sheep incl. lamb	solid	0.6	1.5	0.2	0.0
goat incl. Lamb	solid	0.6	1.5	0.2	0.0

Source: KTBL (2004) and http://www.liz-online.de

Bisher erschienene Forschungsberichte:

1/2006 **Gamer, Wilhelm, Jürgen Zeddies:** Bilanzen von potenziell umweltbelastenden Nährstoffen (N, P, K und S) der Landwirtschaft in Baden-Württemberg

2/2006 **Pohl, Tobias, Oliver Henniges:** Ausdehnungspotenzial des Zuckerrohranbaus in Zentral-Süd-Brasilien unter Berücksichtigung ökonomischer, ökologischer und sozialer Aspekte

3/2006 **Zeddies, Götz:** Gesamtwirtschaftliche Effekte der Förderung regenerativer Energien, insbesondere der Biomasse – Eine kritische Beurteilung vor dem Hintergrund modelltheoretischer Konzeptionen

4/2006 **Schüttel, Carsten, Oliver Henniges:** Positionen der deutschen Mineralöl- und Automobilunternehmen zu Biokraftstoffen unter spezieller Berücksichtigung einer Beimischung von Bioethanol zu Ottokraftstoffen

5/2006 **Zeddies, Jürgen, Manfred Köhne, Enno Bahrs, Christian Janze, Wilhelm Gamer und Beate Zimmermann:** Comparison of the accounting standards used in FADN with the International Accounting Standards (IAS)

6/2006 **Zeddies, Jürgen:** Rohstoffverfügbarkeit für die Produktion von Biokraftstoffen in Deutschland und in der EU-25 (deut. Version)

The Availability of Raw Materials for the Production of Biofuels in Germany and in the EU-25 (engl. Version)

7/2006 **Zeddies, Jürgen, Ludwig Gekle:** Zur Weiterentwicklung der Beitragsbemessung in der Landwirtschaftlichen Berufsgenossenschaft Baden-Württemberg

8/2008 **Potchanasin, Chakrit:** Simulation of the Sustainability of Farming Systems in Northern Thailand

9/2008 **Barning, Roland:** Economic Evaluation of Nitrogen Application in the North China Plain

10/2009 **Schönleber, Nicole:** Entwicklung der Nahrungsmittelnachfrage und der Angebotspotenziale der Landwirtschaft in der Europäischen Union

11/2009 **Schweizer, Tobias:** Agricultural potential of bioenergy production in Peru - With special focus on the impact on smallholders using the example of Jatropha curcas

12/2011 **Blank, Daniel:** Agriculture as Emission Source and Carbon Sink: Economic-Ecological Modelling for the EU-15