

climate changes spatial planning

Integration

Integrated analysis of emission reduction over regions, sectors, sources and greenhouse gases

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Summary

Summary in Dutch

Na CO_2 emissies uit energieproductie en –gebruik leveren broeikasgasemissies uit landgebruik de grootste bijdrage aan de stijgende concentraties in de atmosfeer, die verantwoordelijk zijn voor klimaatverandering. In emissiereductie strategieën wordt echter weinig aandacht gegeven aan de rol voor landgebruik emissies, onder andere doordat er relatief minder bekend is over hun herkomst en (procesmatige) oorzaken. Wel blijkt op basis van tentatieve top-down schattingen dat er een aanzienlijk reductiepotentieel tegen relatief lage kosten zou bestaan, dat bij effectieve benutting minder klimaatrisico's tegen lagere kosten kan betekenen. Daarnaast staan landgebonden opties als bio-energie, koolstofplantages, bosbeheer en tegengaan van ontbossing in toenemende mate in de belangstelling.

Over de sterkte van de vele landgebruik gerelateerde BKG bronnen bestaan wel ramingen, gebaseerd op veldstudies, modelstudies, inverse modellering en andere methoden. Desondanks zijn er veel onzekerheden, ook rond de achterliggende processen en hun relatie met (veranderingen in) landgebruik. Bij die veranderingen in landgebruik spelen multi-schaal koppelingen een belangrijke rol: naast doorgaande groei in landbouwproductie leiden veranderingen in EU landbouwbeleid en mondiaal handelsbeleid tot uiteenlopende vraag naar landbouwproductie in de EU en in Nederland, waarmee zowel de onbestreden emissies als de beschikbare mitigatie-opties beïnvloed worden.

Er is gekeken naar de modellering van landgebruik, bijbehorende emissies en (netto) mitigatie potentiëlen op mondiale schaal, met meer gedetailleerde inzoom op de lidstaten van de EU. De gestileerde weergave van landgebruiksprocessen en -emssies werden daarbij getoetst aan meer gedetailleerde modellen en databases op nationale en EU schaal, om te onderzoeken of en in hoeverre de beoogde schaalkoppelingen intern consistent gemaakt konden worden.

Einddoel was om uitgaande van integrale, mondiale klimaatstrategieën te bepalen wat de bijdrage van de Nederlandse landgebruiks sectoren aan het bereiken daarvan kan zijn. Om dat hele spectrum te kunnen bestrijken zijn allerlei deelresultaten geboekt, waaronder verbeterde procesmodellen, ruimtelijke allocatie van landgebruik(verandering), landgebruiks scenarios i.r.t. tot toekomstige consumptiepatronen, productiesystemen en handelsregimes, databases met mitigatie opties

Enerzijds zijn de resultaten van belang voor Nederlandse beleidsmakers bij het bepalen van de mogelijke rol van landgebruiks opties in overall strategieën. Anderzijds kunnen vertegenwoordigers uit sectoren als landbouw, bosbouw en natuurbeheer hun positie bepalen t.o.v. andere sectoren en andere schaalniveaus voor wat betreft hun bijdrage aan emissies, respectievelijk aan het terugdringen daarvan.

Summary

After CO_2 emissions from energy production and use, greenhouse gas emissions from land use provide the greatest contribution to increasing concentrations in the atmosphere responsible for climate change. In emission reduction strategies is little attention given to the role of land use issues, because there is partially less known about their origin and (process-related) causes. It does

appear, based on tentative top-down estimates, that a significant reduction potential at relative low cost would be, which could mean less climate risks at lower costs if used effectively. In addition, land-related options such as bio-energy, carbon plantations, forest management and combating deforestation are increasingly gaining interest.

The strength of many land-use related GHG sources do depend on estimates, based on field studies, pilot studies, inverse modeling and other methods. Nevertheless, there are many uncertainties, even concerning the underlying processes and their relationship with (changes in) land use. With these changes in land use multi-scale coupling are playing an important role: in addition to continued growth in agricultural production changes in EU agricultural policy and global trade policies result into varying demand for agricultural production in the EU and the Netherlands which affects both the undisputed emissions and the available mitigation options.

Consideration was given to the modeling of land use, related emissions (net) and mitigation potentials on a global scale with more detailed focus on the EU Member States. The representation of land use processes and resulting emissions were tested with more detailed models and databases on national and EU levels, to determine whether and to what extent the intended scale links could be made consistent internally.

The endgoal was to determine the contribution of the Dutch land use sectors to integrated, comprehensive global climate strategies. To cover the entire spectrum, progress has been made by improving process models, better implementation of spatial allocation of land use (change), new land-use scenarios in relation to future consumption, production and trade regimes, and databases with mitigation options.

On one hand, the results are important for Dutch policymakers in determining the possible role of land use options in overall strategies. On the other hand, representatives from sectors such as agriculture, forestry and nature are now better able to determine their position compared to other sectors and other levels in terms of their contribution to emissions or to reduce it.

Extended summary

The basic idea of the project is to establish a multi-scale information system on LULUCF emissions under baseline conditions and under overall mitigation targets and policies. Local, regional and sectoral stakeholders at the national level can base their decisions on detailed assessment of mitigation options and potentials, but also on the broader context of European and global strategies. The assessment will be framed by alternative assumptions on future land-use and land-cover, influenced by changing agricultural and trade policies as well as on boundary conditions associated with environmental and ecological concerns. The European level plays a key role as the primary source of agricultural and environmental policies that shape the conditions for the Netherlands. The global trends are then in turn addressed as backdrop for the European developments.

The number of options available to mitigate emissions investigated in this project are: Livestock management (re-allocation of farms, reduced protein content of feed and changes in feed intake/additives), Housing and manure storage (low ammonia emissions housing and storage), Nutrient management (balanced fertilization, maximum nutrient application rate, manure incorporation, fertilizer/manure placement, urea substitution, manure digestion, Crop (residue) management (rotations, catch crops, adding legumes, reduced residue removal, Soil and water management (reduced tillage, zero tillage, restoration Histosoils), Forest management (improving forest sink function, better understanding forest carbon fluxes and pools on high resolution), Food management (consumption changes in Food Chains) see table 2.

The potential environmental impacts of food chains in high income and developing countries play an important role. Analysis showed that the environmental impact of the food systems can be reduced through changes in consumptions patterns of high-impact foods such as beef, which has a large impact during the agricultural phase. It is during that phase that many other measurements can be taken in order to reduce emissions, apart from reducing energy intensive transport and processing stages.

European forests now sequester some 100 Tg C/yr which is very significant in comparison to the 900 Tg C/yr of fossil fuel based emissions in the current EU. In relation to this, some activities related to forests, afforestation and forest management may be used to meet the emission reduction target agreed under the Kyoto Protocol. Forests, however, fulfill a multitude of functions and their management is heavily influenced by developments in e.g. the wood market. Also, the forest area (changes) are influenced by the Common Agricultural Policy (CAP) of the European Union. Thus trading off the various functions of forests to maximize their contribution to fulfill them is an integral part when assessing measures to increase carbon sequestration in forests. Though there is ample evidence that the agricultural and forestry sector may significantly contribute to achieving the objectives of the Kyoto protocol, there are still large uncertainties about the effectiveness of the various policies and measures that may be taken. Furthermore, effectiveness of single measures mostly depends on other actions and re-location of activities at farm or regional level, or on trade-offs with other gases and with other non-greenhouse gas emissions and policies. Therefore interactions, feed backs and trade-offs are to be evaluated in the context of socio-economic opportunities and constraints of mitigation strategies. The focus is on the mitigation of direct and indirect N_2O, CH_4 and CO_2 emissions from agriculture, but the potential risk of increased N_2O emissions following C sequestration in soils is also considered (Kros et al., 2011a).

Land-use developments in European countries are strongly influenced by many drivers among which the EU policies, e.g. the Common Agricultural Policy and directives relating to conservation of natural ecosystems. If and when land-use related emission reductions are considered, clearly the future claims on available land to satisfy a variety of demands and services play a crucial role. Competition for land arises from its use to grow food and fodder, graze cattle, supply biomass (incl. timber, pulp & paper and other organic materials), serve as carbon sinks and provide space for human activities (housing, infrastructure, recreation grounds), etc. Furthermore, natural ecosystems and biodiversity must be protected despite the increasing stresses imposed by human activities (e.g. Stehfest et al., 2009).

Global LU scenarios were developed in this project and these scenario studies have been an important input to the BSIK-IC2 project, and were used in the development and application of tools. E.g. they have been already applied for the OECD's global environmental outlook 2008 (OECD, 2008, MNP, 2008), and IPCC's upcoming 5th assessment report (van Vuuren et al. 2010). They all include a baseline development for land use and land use emissions, and several mitigation scenarios, which address land based mitigation options in a "conventional way", i.e. only include technical options to reduce mostly NO_2 and CH_4 emissions from fertilizer application, manure, and rice cultivating.

Further options to reduce land-related emissions, also including behavioral changes, have been investigated with respect to livestock consumption (Stehfest et al, 2009), and have been further elaborated for a number of production and consumption options (PBL, forthcoming, Stehfest et al., in review). Forest management constitutes another important option to reduce CO_2 emissions or increase the CO_2 storage on land, and has been addressed in recent model development and scenario studies (see ten Brink et al. 2010, and Oorschot et al, forthcoming). With respect to European studies, several BSIK-IC applications make use of scenarios developed under the EUruralis framework, in cooperation between LEI and PBL (e.g. Neumann et al., in press, deVries et al. 2010). Some BSIK-IC2 work on further land-related mitigation options, like expansion of irrigation, and potentials to reduce the yield gap (Neumann et al. 2010, Neumann et al., in revision), will only be used in future scenario studies.

Land use management and mitigation options were explored at the landscape scale using the INITIATOR model (Kros et al., 2011a), the regional (provincial) scale using the INITIATOR model (Kros et al., 2011b) and the European scale using both the INTEGRATOR model (Kros et al., 2010) and the MITERRA model (Velthof et al., 2009; Lesschen et al., 2009; Lesschen et al., in prep). Results suggest that on the landscape level low protein feeding and restrictive fertilizer application had the largest effect on both N inputs and N losses, resulting in a N deposition reduction on Natura 2000 sites of 10% and 12%, respectively. At the regional level the comparatively most cost-efficient measures were low-emission application, followed by measures to reduce the protein content in feed. Relocating farms sites was very cost inefficient. Finally, at the European level the MITERRA model was linked to the Eururalis framework (Lesschen et al, 2009). The following measures were included: reduced and zero tillage, increased carbon input, efficient fertilizer use and methane reduction. The analysis of the measures showed that the impact of mitigation measures on GHG emissions is much larger than the impact of different financial options in the Common Agricultural Policy. Full implementation of the simulated mitigation measures could lead to a reduction of GHG emissions from agriculture by 127 Mton CO_2-eq yr^{-1}, which is about a quarter of the current GHG emissions from agriculture. Promoting mitigation measures is therefore more effective than influencing income and price subsidies within the CAP to reduce GHG emissions from agriculture.

Several tools were developed during this project, e.g. in order to gain more insight and to increase knowledge on how to apply a crop growth model at the global scale. One important question existed with respect to scaling up existing field-scale crop models to the global scale. Also knowledge was gained on agricultural land management and land use intensity. First, agricultural land management and land use intensity depend only to a certain degree on characteristics of the land itself. Socio-economic and political factors, for example population density, market accessibility, and political stability explain the spatial variability of agricultural land management and land use intensity as well. Second, land use and land use management often have a strong path dependency as they go along with long-term investments (e.g., irrigation equipment, farming infrastructure). The current agricultural land management can therefore only to some degree explain what has triggered intensification in the past. Third, factors explaining differences in agricultural land management at one scale may be differently important at another scale. Hence, their influence cannot be assumed to behave linearly across scales. Identifying drivers of land management change should therefore always be done at the spatial scale of interest.

In order to derive a spatially improved carbon balance for the European forests, three approaches were followed. First, the forest resources scenario model EFISCEN was improved. Second, an attempt was made to assess the spatial variability in forest carbon fluxes through direct modeling on forest inventory plots from different countries, and third, the development of a 1 km^2 resolution forest resource scenario model with pan-European extent was started, enabling scaling between local and continental scale processes.

Finally, the evaluation of scenarios and mitigation options resulted in an important outcome: studies with the IMAGE model confirms the notion that LU reduction percentages emerging from the global scale can serve as a boundary condition for more in-depth LU mitigation analysis at a finer scale, not only for baseline emissions but also for reduction potentials as well.

1. Introduction

Second to CO_2 emissions from fossil fuel combustion only, land-use activities are the largest source of greenhouse gas (GHG) emissions at the global scale (IPCC, 2001a). In many currently less developed countries, the share of land-use and land-use change related emissions is even larger and occasionally the largest contributor to total emissions. Costs of emission mitigation can be significantly reduced if measures can be selected from as wide a range of options as possible [IPCC, 2001b]. This suggests that policy strategies should allow to exploit the potential benefits of flexibility across sources, gases, location and timing of reduction options; clearly without losing sight of undesirable side-effects and conflicts with other aspirations and concerns.

It is widely recognized that cost-effective strategies to reduce the risk of climate change by lowering future (net) emissions of greenhouse gases (GHGs) should consider where possible all relevant sectors, (net) sources and greenhouse gases at the global scale. In most integrated mitigation analysis tools used to date, land-use related mitigation options are at best treated in a rather simplified manner compared to detailed and comprehensive coverage of energy and industry related sources of GHGs. This study aims to provide an overall assessment framework (building on information gathered in other BSIK projects) that allows for a fair and equitable treatment of options to reduce GHG emissions or enhance the sinks.

GHG emission projections under a wide array of scenario assumptions indicate that CO_2 from fossil fuel combustion will remain the dominant contributor to radiative forcing at the global scale over the next century [Nakicenovic, 2000]. However, the contribution of land-use related sources and sinks to the total GHG emissions of developing countries is typically much higher than for the industrialized world, which constitutes a sizeable potential for reduction under the Kyoto mechanisms. Besides CO_2, other GHG gases such as methane and nitrous oxide need to be considered as well, mostly originating from agriculture.

In Europe, the food and agro businesses together account for more than 20% of total energy and material use, and about 20% of the GHG emissions. The sector also occupies by far the largest land areas in Europe and abroad. In recent years the efficiency of core production processes has generally increased, while at the same time, several developments have compensated and – in many cases – even outweighed these gains, resulting in an increase in resource use in absolute terms. More stringent hygiene and food safety requirements and changing consumer patterns lead to large-scale production facilities throughout Europe and to larger transportation distances. The latter contributes not only to higher energy use and greenhouse gas emissions, but also to land-use claims for infrastructure. On the other hand, the land use related to agriculture and horticulture in Europe is decreasing, mainly due to the ongoing structural change in agricultural production, increasing yields and imports from other world regions.

Forests play an important role in the European carbon budget through sequestering about 10% of the total EU fossil fuel emissions. Therefore, forest management and afforestation activities may expand or enhance this sink function. There should be a trade off with other influences such as developments in e.g. the wood market, and forest area (changes) influenced by the Common Agricultural Policy (CAP) of the European Union.

The future of the EU agricultural policies, specifically after the recent extensions, is expected to decisively alter the future setting at the European scale. Hence any national land-use analysis cannot give meaningful insights unless performed in the context of alternative European scale developments. That in turn is likely to be affected by future developments of worldwide trade regimes, in particular relevant for trade in agricultural products between world regions and countries.

This research will provide tools to account for the international context for land-use related emission mitigation for consideration by Dutch stakeholders by improving the land use module of an integrated analysis tool, a further development of the IMAGE 2.2 model. Not only will the resolution of the spatially explicit allocation be improved, also the allocation procedures and the productivity processes will be better modeled using up-to-date-insights and approaches. The context for future land-use scenarios will be explored in order to evaluate the potential for associated emissions and reduction options. By assessing land-use changes at the international levels and the associated emissions and reduction options in comprehensive policies towards achieving overall climate targets, adequate and (cost-)effective strategies can be identified, all this while tracking the potential impacts on land uses from climatic change. Specific areas of relevance at the European scale that are addressed in more detail include: the role of European agricultural soils and forests, taking into account land abandonment and changes in land-use and land-cover, influenced also by changing trends in agricultural and food production chains following consumer preferences and concerns.

2. Organisation of the IC2 Project

The basic idea of the project is to establish a multi-scale information system on LULUCF emissions under baseline conditions and under overall mitigation targets and policies. Local, regional and sectoral stakeholders at the national level will be able to base their decisions on detailed assessment of mitigation options and potentials, but also on the broader context of European and global strategies. Moreover, the assessment at this level will be framed by alternative assumptions on future land-use and land-cover, influenced by changing agricultural and trade policies as well as on boundary conditions associated with environmental and ecological concerns. A key role is foreseen for the European level, at the same time the primary source of agricultural and environmental policies that shape the conditions for the Netherlands, but also less studied in integrated assessment. The global trends are then in turn addressed as backdrop for the European developments. For example to explore the impact of new international trade regimes on the agricultural production and trade, or the contribution of LULUCF mitigation actions at various scales to global climate targets and associated burden sharing regimes.

The three core elements of the approach are: i) Development of scenarios, mitigation options and databases (see Chapter 3). Region specific scenario drivers are defined by 24 world regions and 31 European countries. The integral approach for the scenarios links demographics and macro-economics (incl. trade) with food demand (function of GDP and socio-cultural preferences) and supply from physical process modeling. Most output is done at a spatially explicit representation of LU/LC with different grid sizes at the global, European, national, regional and local scale. ii) Development of tools (Chapter 4) which includes a nested set of models from the Global to the European to the national and/or local/plot-scale iii) Evaluation of scenarios, mitigation options (see Chapter 5), where the assessment of the impacts of overall emission reduction strategies focuses on LU/LC: from global climate targets (e.g. GHG concentration levels or temperature change) to international, sectoral and forcing agent contributions, including C-sinks. In close cooperation with the EU project Nitro-Europe, Alterra booked significant progress on making an assessment of the effect of mitigation options included in the models and performing scenario analysis, including land use changes. This was done with the two models INTEGRATOR/MITERRA and INITIATOR2. Several presentations and publications, often jointly with other studies, were produced in 2009 and 2010.

This project is a combined effort of several institutes and many people have been involved. A short overview on alphabetical order is listed here:

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Table 1.
Outline of milestones in the project.

	Milestones for scientific output	Status	2006	2007	2008	2009	2010
W1	**Development of scenarios, mitigation options and databases:**						
a	Overview LU options	Finished				X	
b	Food chains: current and trends	Finished		X			
c	Food chains scenarios EU-25	Finished			X		
d	Forest-sinks potentials	Finished			X		X
e	EU-25 LU scenarios	Finished				X	
f	Global LU scenarios	Finished					X
g	LU management and mitigation options	Finished					X
W2	**Development of tools:**						
a	Land allocation model in IAM	Finished				X	
b	Spatially improved carbon balance	Finished			X		
c	Crop models in IAM	Finished					X
d	Emission reduction allocation module	Delayed					
W3	**Evaluation of scenarios and mitigation options:**						
a	LU emissions and mitigation scenarios	Finished					X
b	Effectiveness of mitigation options and strategies in Dutch and European agricultural systems.	Finished				X	
c	Food chain LU, emissions and mitigation	Finished					X
W4	**Publications:**						
a	Draft PhD thesis Crop Modeling	Ongoing					X[1]
b	Draft PhD thesis Land Use Allocation	Finished					X
c	Publications in peer-reviewed journals	Ongoing		X	X	X	X
	Midterm/final review	Finished			X		X

1 While all other milestones are on track to be finished by end 2010 at the latest, this PhD thesis will not be finalized until November 2011. Contributions anticipated to other milestones are still to be delivered timely.

3. Development of scenarios, mitigation options and databases

3.1 Overview LU options

There have been a number different mitigation options identified in the project, spanning several sectors and operating on different scales. Evaluated options are: **Livestock management** (re-allocation of farms, reduced protein content of feed and changes in feed intake/additives), **Housing and manure storage** (low ammonia emissions housing and storage), **Nutrient management** (balanced fertilization, maximum nutrient application rate, manure incorporation, fertilizer/manure placement, urea substitution, manure digestion, Crop (residue) management (rotations, catch crops, adding legumes, reduced residue removal, **Soil and water management** (reduced tillage, zero tillage, restoration Histosoils), **Forest management** (improving forest sink function, better understanding forest carbon fluxes and pools on high resolution), **Food management** (consumption changes in Food Chains). The next chapters will go into more detail on these management options. Table 2 presents an overview of potential mitigation options, please note that not all options are explored because they are currently not implemented in the models used.

Table 2.
Measures to mitigate nitrogen and greenhouse gas emissions from agriculture (excl. energy use)*.

Management category	Measure**	existing policy***	Significant effect on emissions						Model	
			N_2O	NH_3	NO_X	NO_3	CH_4	CO_2	MITERRA	INITIATOR2
Livestock management	Reduced protein content of feed	o	X	X	X	X	X	?	X	X
	Increased digestibility of feed	-					X	?		
	Feeding: Fat in the diet	-					X	?		
	Additives to feed	-					X			
	Breeding	-	X	X	X	X	X	?		
Housing and manure storage	Low ammonia emission housing and storage	A	X	X	X	X	?		X	X
	Low leaching housing and storage	A	X	X	X	X	?		X	X
	Manure storage time	ND	X	X	X	X	X			
	Storage at low temperature	-		X			X			
	Changes in type of manure (slurry - solid)	-	X	X	X	?	X		X	
	Digestion of manure	-	?	?	?	?	X			
	Composting of manure	-	X	?	?	?	X			
	Treatment/ incineration of manure	-	X	X	X	X	X	X	X	X
	Additives to manure	-	X	X			X			

Management category	Measure**	existing policy***	Significant effect on emissions						Model	
			N_2O	NH_3	NO_X	NO_3	CH_4	CO_2	MITERRA	INITIATOR2
Nutrient management; soil	Balanced fertilization	ND & A	X	X	X	X			X	
	Maximum manure application rate	ND	X	X	X	X		X	X	
	Fertilizer/ manure placement	o	X	X	X	X				
	Fertilizer/ manure incorporation	ND & A	X	X	X	X			X	
	Fertilizer/ manure timing	ND	X	X	X	X				
	Fertilizer type (urea, NH_4, NO_3)	o	X	X	X	X			X	
	Precision farming	-	X	X	X	X				
	Fertilizer free zones/riparian zones	ND	X		X	X			X	X
	Slow release fertilizers	-	X		X	X				
	Nitrification inhibitors	-	X		X	X				
	Livestock grazing intensity	o	X	X	X	X		X	X	X
	Application of organic products	-	X	X	X	X		X		

Management category	Measure**	existing policy***	Significant effect on emissions						Model	
			N_2O	NH_3	NO_x	NO_3	CH_4	CO_2	MITERRA	INITIATOR2
Crop (residue) management; including grassland	Increased productivity	-	X		X	X		X	X	
	Rotations	-	X		X	X		X		
	Catch crops	ND	X		X	X		X	X	X
	Improved cultivars	-	X		X	X		X		
	Reduced residue removal	-	X		X	X		X	X	
	Reduced residue burning	-	X		X	X		X		
	Restriction to ploughing of grasslands	ND	X		X	X		X		
Water, soil and other	Reduced tillage	-	X		X	X		X		
	Zero tillage	-	X		X	X		X		
	Irrigation	-	X		X	X		X		
	Drainage	-	X		X	X		X		
	Improved water management	-	X		X	X		X		X
	Restoration histosols	-	X		X	X		X		

*The number of livestock, land use and crop area are defined in the scenarios and not changed by measures.
** in a later stage measures must be more specific, e.g. changes in feeding of pigs, catch crops after certain crops in certain regions etc.
*** measures that already have to be taken or should be taken in the near future at implementation of environmental policies.
ND = nitrate directive, A = ammonia policy.
- = not in existing environmental policy.

It is worth noting that all measures listed in Table 2 have an effect on multiple emissions, as shown in Table 2, and that some emissions have an effect on multiple environmental pressures such as air quality, acidification, eutrification and climate change, with varying spatial and temporal scales. Measures improving in one domains can work out positive in other domains (synergy) or negative (trade-off). Therefore it is not straightforward to assign costs to measures in terms of €/t CO_2-equivalent. Recognizing that some measures are being taken for different purposes than reducing greenhouse gas emissions, for example the nitrate directive (ND) or ammonia policy (A) in Table 2, they can be regarded as delivering GHG reduction at no additional cost.

3.2 Food chains

An important question was what are the past and future environmental impacts of the total food chain in high-income and in developing countries? This part of the project assessed the trends in food consumption and food-related environmental impacts (in terms of energy use, greenhouse gas emissions and land use) for three regions: Western Europe, the USA and China. The environmental impacts were determined by two methods: a product level analysis, in which the energy and emissions per kilogramme of 19 products was calculated; and a system level analysis, in which the energy use and emissions of each stage in the process chain (i.e. agriculture, fertilizer manufacture, food processing, transportation and packaging) was assessed for all food products combined. The energy use and GHG emissions for the entire food system (from cradle to factory gate), were estimated at 12.0 MJ/cap and 1.97 tCO_2-eq/cap in Western Europe; 15.1 MJ/cap and 2.83 tCO_2-eq/cap in the USA; and 4.1 MJ/cap and 0.88 tCO_2-eq/cap in China for 2000. In the developed regions, per capita energy use has increased on average around 1% per year since 1970, whereas in China it has increased more than twice as rapidly. Per capita greenhouse gas emissions from the food system have declined slightly from 1970 levels in the USA and have remained unchanged in Western Europe, however they have increased at an average rate of 1.6% per year in China. The diverging trend in energy and GHG emissions can be traced to non-energy sources of emissions during agriculture. Stabilizing cattle populations and fertilizer application rates in Western Europe and the USA have held back the growth of agricultural emissions, which accounted for 60% of emissions from the food system in Western Europe in 2000. Non-grazing land use has also stabilized in Western Europe and the USA as yield improvements have kept pace with population increases and consumption pattern shifts. In China the rapid increase of meat consumption – from 9kg/cap in 1970 to 47 kg/cap in 2000 – has outweighed yield improvements, resulting in an increasing requirement for land. A significant share of the increasing land used for oil seed production is taking place abroad. Scenarios were developed for the future, revealing that, if the current trends continue, per capita energy use will increase by 30-40% between 2000 and 2050 in the developed regions and by over 200% in China. The increase is driven by transport and processing stages. The environmental impact of the food system can be reduced through consumption changes of high-impact foods, especially beef, which has a disproportionately large impact during agriculture. Furthermore, increased attention should be given to measures that reduce emissions during agriculture, because this stage is so large. Action should be taken to limit the growth of energy use and emissions in the transport and processing stages, as they are on track to increase strongly in the future.

3.3 Forest-sinks potentials

For improvements on the modeling of the potential of European forests to act as carbon sink, simulation runs of IMAGE and EFISCEN were compared. This comparison showed that effects of aging were represented differently between the two models. However, due to the delayed implementation of LPJ within IMAGE, no further actions were taken at this time. Furthermore, in combination with several other projects, an analysis of hotspots in the European forest carbon cycle was performed (Nabuurs et al. 2008).

3.4 LU scenarios

With respect to land use scenarios, PBL has completed a number of studies during the last years. These scenario studies have been an important input to the BSIK-IC2 project, and were used in the development and application of tools. Among the global scenarios are the OECD's global environmental outlook 2008 (OECD, 2008, MNP, 2008), and the scenarios developed for the IPCC's upcoming 5th assessment report (van Vuuren et al. 2010). These scenario studies all include a baseline development for land use and land use emissions, and several mitigation scenarios, which address land based mitigation options in a "conventional way", i.e. only include technical options to reduce mostly NO_2 and CH_4 emissions from fertilizer application, manure, and rice cultivating. Further options to reduce land-related emissions, also including behavioral changes, have been investigated with respect to livestock consumption (Stehfest et al, 2009), and have been further elaborated for a number of production and consumption options (MNP, forthcoming, Stehfest et al., in review). Forest management constitutes another important option to reduce CO_2 emissions or increase the CO_2 storage on land, and has been addressed in recent model development and scenario studies (see ten Brink et al. 2010, and Oorschot et al, forthcoming).
With respect to European studies, several BSIK-IC applications make use of scenarios developed under the EUruralis framework, in cooperation between LEI and PBL (e.g. Neumann et al., in press?, deVries et al. 2010). Some BSIK-IC2 work on further land-related mitigation options, like expansion of irrigation, and potentials to reduce the yield gap (Neumann et al. 2010, Neumann et al., in revision), will only be used in future scenario studies.

3.5 LU management and mitigation options

Land use management and mitigation options have been analyzed at three different spatial scales: the landscape scale, using the INITIATOR model (Kros et al., 2011a), the regional (provincial) scale using the INITIATOR model (Kros et al., 2011b) and the European scale using both the INTEGRATOR model (Kros et al., 2010) and the MITERRA model (Velthof et al., 2009; Lesschen et al., 2009; Lesschen et al., in prep). An overview of the evaluated measures is given in Table 3. The evaluated measures at landscape scale were applied in the Noordelijke Friese Wouden (NFW), a landscape in the northern part of the Netherlands, where farmers joined in a cooperative, trying to achieve environmental goals at regional level rather than at farm level. The measures are especially focused on achieving landscape targets on ammonia emission and nitrogen leaching to surface water. The regional scale study describes the quantification of effects of agricultural measures on the reduction in nitrogen deposition on Natura 2000 sites in the Dutch province Overijssel, including both measures to reduce ammonia emission and spatial planning measures, such as reallocation of farms. At the European scale measures are related to European Union (EU-27) wide N_2O emission estimates for the agricultural sector, evaluated by both the INTEGRATOR and MITERRA model and on EU-27 CH_4 emissions and C sequestration using the MITERRA model only. The description and parameterization of the measures can be found in the respective publications.

Table 3.
Overview of the evaluated agricultural management and mitigation options.

Mitigation option	Effect [1)]	Scale and model [2)]			
		Landscape	Regional (provincial)	Europe	
		INITIATOR	INITIATOR	INTEGRATOR	MITERRA
Livestock management					
Reallocation farms	N_{in}		x		
Reduced protein content of feed	N_{in}	x	x	x	x
Changes in feed intake/feed additives	CH_4				x
Housing and manure storage					
Low ammonia emission housing and storage	NH_3	x	x	x	
Nutrient management					
Balanced fertilization	N_{in}			x	x
Maximum manure application rate	N_{in}	x		x	
Manure incorporation	NH_3, N_2O		x	x	
Fertilizer/manure placement	N_{le}				x
Urea substitution	N_2O			x	
Manure digestion	CH_4				x
Crop (residue) management					
Rotations	N_{le}, SOC				x
Catch crops	N_{le}, N_2O, SOC				x
Adding legumes	N_{in}, SOC				x
Reduced residue removal	SOC				x
Soil and water management					
Reduced tillage	SOC				x
Zero tillage	SOC, N_2O				x
Restoration Histosols	N_{in}, SOC			x	

1) Indicating which part of the N and C balance is primary affected, N_{in}: N input by manure, fertilizer, fixation or mineralization, NH_3: ammonia emission, N_2O: nitrous oxide emission, N_{le}: nitrogen leaching, SOC: soil organic carbon, CH_4: methane emission
2) 'x' indicates that the measure was included in the performed analyses reported in this report, The mentioned models generally includes more measures as indicated in this table.

4. Development of tools

4.1 Land allocation model in IAM

A large part of this work was embedded in a PhD project, and the main focus was to explore spatial diversity in agricultural land management and land use intensity and to explain their variability across the globe. To meet this objective a variety of quantitative methods were developed and applied at different spatial scales. The PhD project targeted three important aspects of agricultural land management and land use intensity: livestock farming, efficiency of grain production, and irrigation. The research was conducted at the European and global scale.

At the European scale, an explanatory analysis was done to determine the spatial distribution of five different livestock types. Location factors for the occurrence of dairy cattle, beef cattle, and sheep (ruminants), as well as pigs and poultry (monogastrics) were explored to produce a detailed spatial distribution map of livestock densities. Both an expert-based and an empirical approach were applied to disaggregate consistent and harmonized EU-wide regional statistics to 1km grid cells. It was found that both approaches are equally suited to modeling ruminants, while in general, the spatial distribution of monogastrics could be better modeled by applying the empirical approach. In a next step a multi-scale modeling approach was developed to simulate changes in livestock densities between 2000 and 2030. An allocation model was developed to spatially distribute the scenario-specific livestock numbers at the landscape scale according to the scenario assumptions. Results indicate for most of the old EU member countries a decrease in almost all livestock types, which is particularly remarkable for ruminants. In the new EU member countries sheep, goats and pigs are expected to decline while beef cattle and poultry are expected to grow. Livestock densities are expected to increase both within and outside current livestock hotspot regions in the absence of environmental legislations.

At the global scale, efficiencies of grain production and irrigation of cropland were analyzed. First, actual grain yields were disentangled from production efficiencies to explore if and where grain productivity could be increased without increasing management inputs. A stochastic frontier function is explicitly suited for such purpose and was applied to explore the efficiency, maximum attainable yield, and yield gap of global wheat, maize, and rice production. It is shown that the actual grain yield in some regions is already approximating its maximum possible yields while other regions show large yield gaps and therefore tentative larger potential for intensification. One of the factors that turned out to explain global variance in grain production efficiencies is irrigation. Determinants for irrigation were therefore identified in a separate study. Because drivers of irrigation operate at multiple spatial scales we accounted for biophysical determinants mainly at the grid cell level, and for socio-economic and governance determinants at the country level. To identify the variability of the determinants within and amongst these two spatial levels we applied a multilevel analysis. Results show there is a significant clustering of countries in terms of irrigation. The results suggest that in most countries the interplay of biophysical, socio-economic and governance factors influence the likelihood for cropland to be irrigated.

In the final thesis (completed October 2010: Neumann, 2010) three main observations on agricultural land management and land use intensity were made. First, agricultural land management and land use intensity depend only to a certain degree on characteristics of the land itself. Socio-economic and political factors, for example population density, market accessibility, and political stability explain the spatial variability of agricultural land management and land use intensity as well. Second, land use and land use management often have a strong path dependency as they go along with long-term investments (e.g., irrigation equipment, farming infrastructure). The current agricultural land management can therefore only to some degree explain what has triggered intensification in the past. Third, factors explaining differences in agricultural land management at one scale may be differently important at another scale. Hence, their influence cannot be assumed to behave linearly across scales. Identifying drivers of land management change should therefore always be done at the spatial scale of interest.

4.2 Spatially improved carbon balance

In order to derive a spatially improved carbon balance for the European forests, three approaches were followed. First, the forest resources scenario model EFISCEN was improved, second an attempt was made to assess the spatial variability in forest carbon fluxes through direct modeling on forest inventory plots from different countries, and third, the development of a 1 km2 resolution forest resource scenario model with pan-European extent was started, enabling scaling between local and continental scale processes.

The improvements of the EFISCEN model consist of: 1) a finer resolution for the allocation of wood harvest (from national to NUTS-II level, in countries with high variability in wood harvest patterns), 2), updating existing parameter values with those recommended in the Good Practice Guidance 2006 (IPCC 2006), 3) quantifying parameter uncertainties as preparation to a full uncertainty analysis of the EFISCEN model (Schelhaas et al. in prep), 4) and increased detail on the effect of different forest management scenarios on forest resource development and carbon balance (Schelhaas et al. in prep.). This work was done in close collaboration with EFI and partners in FP6 projects Carbo-Europe, NitroEurope and EFORWOOD.

The direct modeling of carbon fluxes on forest inventory plots proved unsuccessful. This approach, where the development of forest inventory plots was projected using the stand-based forest carbon model CO_2FIX (Schelhaas et al 2004), showed that the prediction uncertainty was larger than the actual variability, due to estimation uncertainty of critical parameters (see for an impression Nabuurs et al. 2010).

Finally, the development of the new pan-European forest resource scenario model is showing progress. The distribution of several properties of forest resources was quantified at a 1 km^2 resolution (Gallaun et al. 2010 (forest volume), Brus et al. in prep (tree species map)). Further development of the model will continue within the FP7 projects Motive and GHG-Europe.

4.3 Crop models in IAM

Also this part of the work was also embedded in a PhD project. Aim of the research was to increase knowledge on how to apply a crop growth model at the global scale. Crop growth models are often developed for application at the field scale. Application of these models at larger scales such as for climate change impact assessments or integrated assessment studies has become a common practice. However, for these applications, the required scale and objective of a crop growth model may go beyond the scope of the original model. Several questions existed with respect to scaling up existing field-scale crop models to the global scale; therefore the following aspects were investigated.

Crop models are able to account for the variations in climate and management activities and their effects on crop productivity. Regional applications require consideration of spatial variability in these factors. Several studies have analyzed effects of using spatially aggregated climate data on model outcomes. In addition, we found that bias in model outcomes as a result of using aggregated input data (weather and management activity data, i.e. sowing dates) is small.

Weather data are essential inputs for crop growth models, which are primarily developed for using daily weather data. These data are often not available, especially when models are applied to large regions and/or for future projections. Daily weather data can be generated from aggregated weather data. It is however important to know how sensitive different modeling approaches are to the use of aggregated weather data. We found that increasing detail in a modeling approach results in higher sensitivity to the use of aggregated weather data. This has implications for the choice of a specific approach to model a certain process, if input data with a certain temporal resolution is available.

Good modeling practice dictates to keep models as simple as possible, but enough detail should be incorporated to capture the major processes that determine the system's behavior. By comparing approaches with different levels of detail for light interception and biomass production, we found that using a constant radiation use efficiency under a wide range of climatic conditions may give an over-simplification of the biomass production process, however, more important, particular attention should be given to the choice of the light interception approach in a crop model.

A key input for crop growth models is information on management strategies, e.g. the timing of sowing by farmers. However, existing databases with sowing dates for the global scale are not suitable to provide global crop models with sowing dates under future climatic conditions. Therefore we developed a methodology to simulate sowing dates at the global scale based on climatic conditions only. We showed that we could satisfactory simulate sowing dates under rainfed conditions for various annual crops for large parts of the Earth.

Crop yields are determined for a large part by the duration and timing of phenological phases. Four major components influence the phenological development of a crop: temperature (direct and in case of a winter cultivar indirect via vernalization), photoperiod, sowing date, and the cultivar. Differences exist between cultivars with respect to sensitivity to photoperiodism, vernalization, and temperature. However, information with regard to these differences is lacking at the global scale. We developed a methodology to allow for these cultivar differences in the calculation of harvest dates and showed that the growing period of maize and wheat could be satisfactory simulated at the global scale.

Since the beginning of 2009, the work on crop modeling for IMAGE is conducted in a wider international setting in the form of expert meetings with scientists of Potsdam-Institut für Klimafolgenforschung (PIK), International Institute for Applied Systems Analysis (IIASA), University of Bonn, Wageningen University Research (WUR), and PBL. At PBL, in collaboration with PIK, LPJmL is integrated in and working on a new grid-computing facility, that operates at reasonable computing times.

4.4 Emission reduction allocation module

The emission reduction allocation module (ERAM) of the global integrated assessment framework IMAGE for comprehensive allocation of GHG reduction schemes as has been developed by RIVM and TNO, offers a rigorous approach to balance energy and industry emissions of greenhouse gases and pollutants and to identify cost-effective allocations of future mitigation efforts over radiatively important gases in regions and sources in different. In the present project, land-use related emissions and sinks, reduction potentials, implementation barriers and costs have been added to the ERAM.

ERAM integrates the different costs and emission reduction potentials of all modules, being Timer (CO_2 emissions from energy), TREM (Timer Reduction of (Energy) Emissions Module – non-CO_2 GHG and acidifying emissions), PEM (Process emissions from Industry – GHG and acidifying emissions) and the new developed Land-use Emissions Modules (LEM). The ERAM allocates in an iterative process, emission reductions to different sectors / modules on the basis of cost-effectiveness. For this allocation, TREM and PEM deliver Marginal Abatement Cost curves. Timer delivers the carbon tax that is used in the model to stimulate implementation of CO_2 abatement measures. This information forms the basis for the assessment of a cost-effective abatement strategy over the total of modules. This strategy results in a shadow price for the different pollutants, being the highest marginal cost that has to be paid to reach the overall emission objective. The set of shadow prices is fed back into the different modules which recalculate their scenarios with this new price information. The modified emissions result in adapted emission reduction potentials and costs which form the basis for a new cost-effective allocation over the modules.

Up to now, the LEM was lacking. In this project has been researched how the information on reduction potentials and costs from literature can be derived for the overall cost-effective reduction allocation. This information is framed in scenarios on land use emission potentials from the IMAGE model. This has been done in close consultation with the LEM developers of PBL.

Based upon the theoretical modeling approach chosen to optimize the family of different dynamic modules, a design has been made and the software code has been written.

Through the overall emission reduction mechanism built into the IMAGE framework, cost-effective and/or more equity-based attribution of mitigation efforts to regions, sectors, GHG gases and sources can be demonstrated by a number of cases for one scenario. Currently, ERAM could not be implemented and tested in operational mode in the IMAGE framework, and hence the extension with LEM, relevant for this project, has not been realized.

5. Evaluation of scenarios and mitigation options

5.1 LU Role of Land-Use in GHG emission reduction in the IMAGE RCP-2.6 scenario for the world and for EU-27

The ambition of the project, reflected in the title, was to estimate the potential and role of Land-use (LU) related emissions reduction options at various scales to achieve ambitious long-term climate goals such as the 2-degrees target. In this chapter this is illustrated by the outcomes from the IMAGE model framework under Baseline conditions. E.g. no specific climate policies beyond currently implemented measures such as the EU-ETS (Emissions trading Scheme). These Baseline results are contrasted with a very ambitious, globally implemented variant that leads to a peak radiative forcing of 3 W/m² around the mid of the century, followed by a decline to 2.6 W/m² in 2100. This scenario was developed and implemented as part of the so-called Reference Concentration Pathways process (Moss, 2010) and is labeled RCP2.6 here. More details about the assumptions and results can be found in (Vuuren, 2010).

Under baseline conditions, global annual LU related GHG emissions measured as CO_2-equivalents make up around 17-18% of the total in the years 2030 and 2050. For EU-27[1] the share of LU in the total GHG emissions is more limited: around 12%. This lower share illustrates that LU emissions are less important in highly developed, industrialized regions of the world than in other regions. An important difference is the net contribution from deforestation and regrowth of forests: at the global scale associated with some 2.5% of all GHG emissions in the period 2030-2050, but negligible for the EU-27.

If drastic reductions of GHG emissions are pursued, as explored in the RCP 2.6 scenario, emissions of all gases from all sectors and sources in all world regions are called upon. After peaking around 2020, total global emissions are cut by more than one third compared to the baseline in 2030 and by three quarters in 2050 compared to the baseline. Relatively high income and high emitting regions cut back their domestic emissions even further than the global average, the EU by 45% in 2030 and 80% in 2050, see figure 1.

1 In the IMAGE model, the Eu-27 region is approximated by the sum of the regions Western-Europe and Central-Europe. The inclusion of Norway, Switzerland, Iceland and several smaller former Yugoslav countries leads to a small over-estimation of the share of Europe in the global numbers.

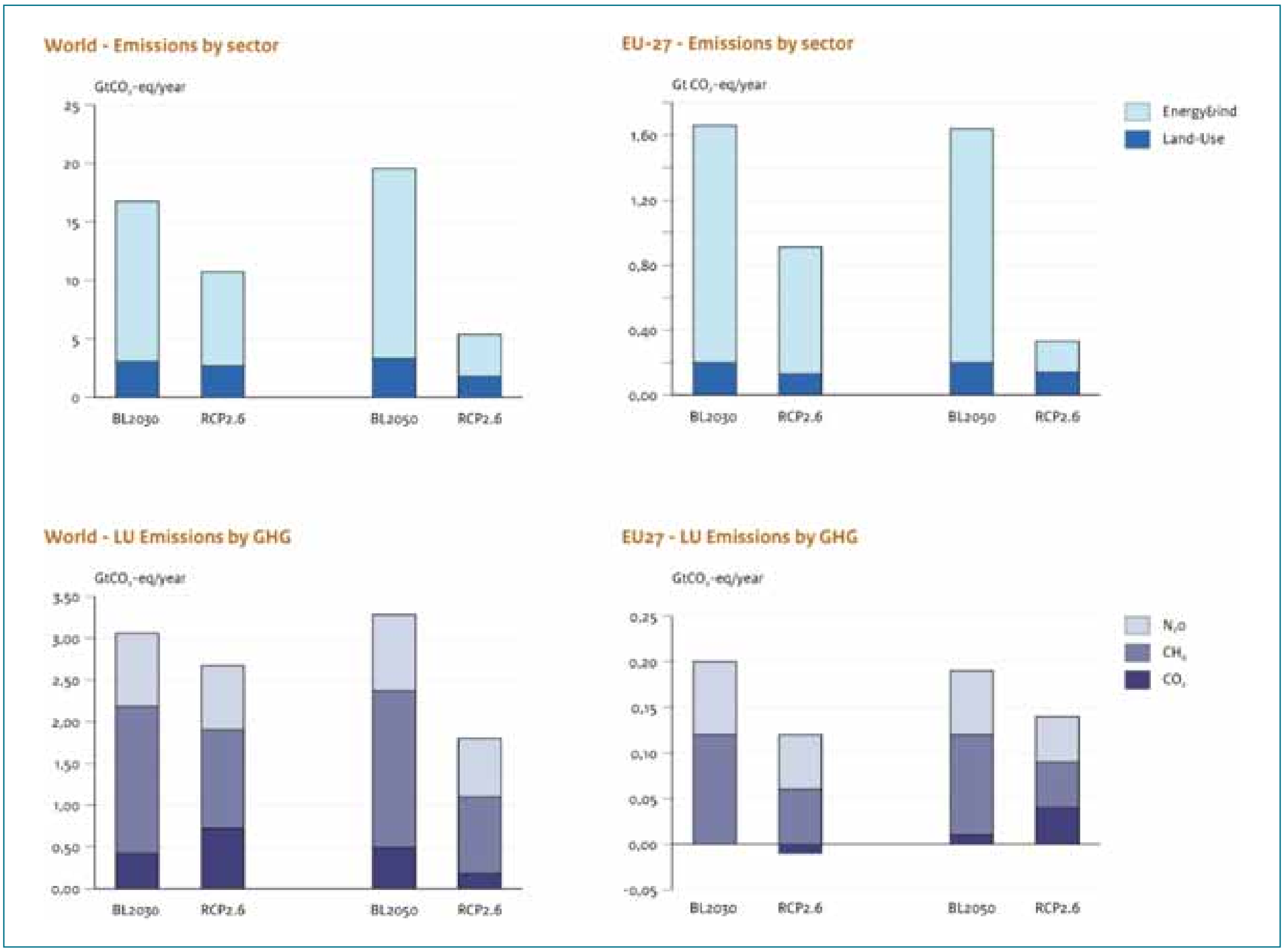

Figure 1.
World and EU27 emissions for 2030 and 2050 for the RCP2.6 scenario, per sector and by GHG.

Both at the global level and in the EU, the contribution of LU related emissions reduction is much less than that of industrial and energy sectors. Given the current understanding of the viable potential of options to reduce LU related emissions, it is difficult to imagine much deeper cuts. In part this is explained by the geographically dispersed nature of farming and livestock operations, but also by the intrinsic linkage of GHG emissions with biological processes such as N_2O emissions from cultivated land. This is illustrated by the reduction of all LU emissions by 46% in the RCP-2.6 scenario at the global scale, while energy & industry emissions are cut by 78% compared to the Baseline. For LU dominated N_2O emissions, the reduction is a mere 23%. As a consequence, the share of LU emissions in 2050 in the RCP-2.6 scenario is relatively high and makes up around one third of the total.

For the EU27 very similar results are found: LU emissions are reduced by 30% in 2050 and make up more than 40% of the emissions remaining. The results found for the EU27 compare well to the findings from the more detailed analysis at the European level reported in section 5.2. This confirms the notion that LU reduction percentages emerging from the global scale analysis with IMAGE can serve as boundary conditions for more in-depth LU mitigation analysis at finer scale. Earlier in this project this was already found to be true for Baseline emissions, now it is confirmed for emission reduction (potentials) also.

An important issue is how LU related emissions reduction compare to those in other sectors in terms of their cost. As indicated in section 3.1, at the level of concrete options evaluated at the finer scale this is far from straightforward and was therefore not tried. At the more aggregated level of EU27 and global, it was anticipated that the ERAM model would deliver the information, especially since it allows to analyze multiple environmental issues in an integrated form, with LEM also covering the land-use sources and sinks central to this project. However, as mentioned in Section 4.4 this line of work was not completed in time. As a consequence, only tentative indications could be derived from the FAIR climate policy model of PBL. In FAIR, allocation of mitigation efforts is done on the basis of estimated Marginal Abatement Cost curves (MACs) per sector and per GHG gas, taking into account global climate targets. In principle, FAIR selects mitigation efforts per gas, region and sector on the basis of equal marginal cost, reflecting basic economic efficiency principles. The results for the same RCP 2.6 scenario shown in Figure 1, indicate that LU related emissions reductions of CH_4 and N_2O are on average 25 to 40% less costly per tCO_2-equivalent than GHG reductions in other sectors.

5.2 Effectiveness of mitigation options and strategies in Dutch and European agricultural systems

LU management and mitigation options have been evaluated at four different spatial scales: the farm scale, using the FARMMIN and NUTMATCH models, the landscape scale, using the INITIATOR model, the regional (provincial) scale using the INITIATOR model and the European scale using the INTEGRATOR model and the MITERRA model (see Section 3.5).

For the farm scale, FARMMIN was used for dairy farms and NUTMATCH was used for arable farms. For dairy farms, the mitigation option with the highest impact was increasing the productivity of cows (kg milk per cow per year). Methane emission by cows is directly related to the intake of energy. A high productivity means that fewer cows are needed for a given amount of milk and thus that maintenance metabolism takes up a smaller fraction of the total energy intake by cows. Thus, at a given level of milk production per ha, an increase in the milk production per cow leads to a decrease in emission of CH_4. A decrease in grazing leads to an increase in methane emission and a decrease in N_2O emission. But with much less grazing at present than in the past, this factor will be relatively unimportant. Soil carbon stock is affected by manure application limit and by the productivity of grass. When there is no application limit, soil organic matter reaches an equilibrium of 4.02%. The value corresponding to the EU's limit of 170 kg N ha^{-1} is 3.63%. It is likely that after many years of heavy fertilization, soils are currently close to the value corresponding to no application limit. Thus, if the limit of 170 kg N ha^{-1} becomes binding in The Netherlands, this will result in a reduction of soil C stocks by up to 9.7%. A change in soil carbon stock implies a (temporary) flux of CO_2. When the changes in soil carbon stocks above are averaged over 50 years, decreasing the manure application limit will lead to an average CO_2 emission of 352 kg CO_2 ha-1 yr-1 for each of the 50 years.

For arable farms, green manures and application of farmyard manure are options to move the CO_2 balance of agriculture in the right direction. However, use of organic fertilizers in the place of mineral fertilizer may lead to higher N losses, including N_2O and NO_3. When the emission of N_2O is expressed in CO_2-equiv. and added to the emission or sequestration of CO_2 from change in soil organic matter, the effect of the various scenarios is small. Livestock farming and arable farming are linked through the exchange of feed and manure. The two types of farming must be considered in tandem when assessing climate change effects. In this study we have not done this.

For the landscape scale, INITIATOR was applied to the Noordelijke Friese Wouden in the northern part of the Netherlands to assess current nitrogen fluxes to air and water and the impact of various agricultural measures on these fluxes, using spatially explicit input data on animal numbers, land use, agricultural management, meteorology and soil (Kros et al., 2011a). Average model results on NH3 deposition and N concentrations in surface water appeared to be comparable to observations, but the deviation was large at local scale, despite the use of high resolution data. Evaluated measures included air scrubbers reducing NH_3 emissions from poultry and pig housing systems, low protein feeding, reduced fertilizer amounts and low-emission stables for cattle. Results are shown in Table 4. Low protein feeding and restrictive fertilizer application had the largest effect on both N inputs and N losses, resulting in a N deposition reduction on Natura 2000 sites of 10% and 12%, respectively. More information is given in Kros et al. (2011a).

Table 4.

The additative effect of measures on the mean NH3 deposition on the Natura 2000 sites and the areal exceedance of the critical N deposition due to the agricultural emissions within in the NFW.

Measures	Mean deposition (mol N ha^{-1} yr^{-1})					Relative change (%)	Exceedance (%)
	NH_3 Housing	NH_3 Application	NH_3 background	NO_x background	Total		
0. Current situation	85	210	710	501	1505	-	14.6
1. Existing policy	81	209	710	501	1500	0.3	14.6
2. Air scrubbers	79	208	710	501	1498	0.5	14.6
3. Reduced protein content	66	157	710	501	1433	4.8	14.5
4. Restrictive manure application	66	116	710	501	1392	7.5	13.9
5. Low-emission stables for cattle	40	118	710	501	1368	9.1	13.4
6. NH_3 emission NFW = 0	0	0	710	501	1211	19.6	4.4

For the regional scale, the efficiency of emission control measures in agriculture on the N deposition and critical N load exceedances in Natura 2000 sites was evaluated, using the Dutch province of Overijssel as a case study. INITIATOR was run with spatially explicit farm data to predict atmospheric emissions of ammonia. These emissions were input of an atmospheric transport model OPS to assess the N deposition on the Natura 2000 sites., Calculations for the year 2006 showed that only 35% of the N deposition on the Natura 2000 sites were caused by agricultural NH_3 emissions within the province. Comparatively most cost-efficient measures were low-emission application, followed by measures to reduce the protein content in feed. Relocating farms out of the Natura 2000 sites was very cost inefficient. Since critical N depositions of the Natura 2000 sites in Overijssel are largely exceeded in more than 90% of the area, the evaluated abatement measures were not effective to reduce the area exceeding critical loads when only applied within the province (Table 5). Reductions of N deposition to a level below critical loads can only be achieved with the support of national and international emission reductions.

Table 5.
Effect of measures on the area exceeding CLN and the average accumulated exceedance of CLN (AAE).

Measures	Effect	
	Area exceeding CLN (%)	AAE (mol ha^{-1} yr^{-1})[a]
0. Current situation	93	1189
1. Current policy	93	1007
2. Air scrubbers	92	960 (-4.7%)
3. Low-emission stables for cattle	91	908 (-9.8%)
4. Reduced protein content	91	911 (-9.5%)
5 Low-emission application	87	889 (-11.7%)
6. 4+5+Organic cattle farms	84	828 (-17.8%)
7. Relocating farms	92	951 (-5.6%)

a Values in bracket denotes the relative change compared to the current situation

For the European scale EU-27 wide N_2O emission estimate for the agricultural sector were calculated, using the INTEGRATOR model, combined with detailed GIS-based environmental data and farming data (Kros et al., 2010). INTEGRATOR links various modules, calculating NH_3, NO_x, N_2O, CO_2 and CH_4 emissions from housing and manure storage systems, agricultural and non-agricultural soils and surface waters, while accounting for the interaction between agricultural and non-agricultural systems through an emission-deposition model for NH_3 and NO_x. The study was limited to N_2O emissions from housing and manure storage systems and agricultural soils. All emissions are based on N_2O emission factors which depend on environment (weather and soil conditions), land use (grassland, arable land, crop residues) and management (type of manure and fertilizer, etc). We assessed the plausibility by a comparison of calculated present nitrous oxide emissions at country level with those derived by more simple emission factor approaches and detailed ecosystem models. The model was used to assess the impact of various farming practice packages to mitigate N_2O emissions (Table 6). For the agricultural sector of the EU-27, a total N_2O emission of 347 kton N_2O-N was calculated for the year 2000, which is comparable to other estimates. The overall achievable reduction in N_2O emissions with the evaluated mitigation measures is about 25%. For the EU-27 the most effective measures are Balanced fertilization and Maximum manure application, but this is highly variable per country (Table 7).

Table 6.
Calculated changes in total nitrous oxide emissions from agricultural systems for EU-27 by INTEGRATOR for various mitigation measures compared to the emissions calculated for the year 2000.

Measure	% change in N_2O emissions per emission type compared to the year 2000				
	Housing and storage	Manure and fertilizer application	Grazing	Soil emissions 1)	Total
Reduced protein content of feed	-1.1%	0.2%	-1.0%	0.0%	-1.9%
Low ammonia emission housing and storage	0.0%	0.0%	0.0%	0.0%	0.0%
Balanced fertilization	0.0%	-9.1%	0.2%	-2.7%	-11.5%
Maximum manure application rate	0.0%	7.7%	-15.0%	0.2%	-7.1%
Manure incorporation	0.0%	0.2%	0.0%	0.0%	0.2%
Urea substitution	0.0%	-0.3%	0.0%	0.0%	-0.3%
Restoration histosols	0.0%	-0.8%	0.0%	-0.2%	-1.0%
All measures	-0.9%	-7.2%	-14.8%	-2.9%	-25.8%

1) Includes emission through soil inputs by deposition, mineralization, fixation and crop residues

In cooperation with the PICCMAT project[2] the mitigation potentials in the EU-27 for a range of agronomic practices were assessed with MITERRA. Zero tillage has the highest mitigation potential, followed by adding legumes, reduced tillage, no removal of crop residues, rotation species and catch crops (5). For mitigation of N_2O emissions the measures optimizing fertilizer application and fertilizer type are most important, while other measures have a low or even negative effect on N_2O. However, this negative effect is in general largely compensated by the positive effect on carbon sequestration. A main conclusion is that there are large regional differences in mitigation potentials. Mitigation measures therefore need to be targeted at national or regional level (Lesschen et al., in prep).

Table 7.
Comparison of mitigation potentials of agronomic practices (Mton CO_2-eq yr^{-1}).

Measure	CO_2	N_2O	Total
Catch crops	9.7	-3.8	5.9
Zero tillage	19.7	-0.50	19.4
Reduced tillage	9.6	0	9.6
Residue management – no removal	8.8	-1.3	7.1
Residue management – composting	1.8	0.64	2.5
Optimizing fertilizer application	0	4.2	4.2
Fertilizer type	0	2.3	2.3
Rotation species	7.7	0.27	8.0
Adding legumes	10.6	0.20	10.8
Agro forestry	0.63	0.021	0.7
Grass in orchards and vineyards	1.8	0.028	1.8

2 http://www.climatechangeintelligence.baastel.be/piccmat/index.php

For the evaluation of four future scenarios on GHG emission from agriculture, the MITERRA model was linked to the Eururalis framework (Lesschen et al., 2009). GHG emissions were assessed for the IPCC SRES scenarios (A1, A2, B1 and B2) up to 2030. The following measures were included: reduced and zero tillage, increased carbon input, efficient fertilizer use and methane reduction. In 2000 GHG emissions from agriculture in the EU-27 were 529 Mton CO_2-eq yr^{-1}. This is about 13% of the total GHG emission in Europe. For 2030 the projected GHG emissions from agriculture decreased in all scenarios, ranging between 397 Mton CO_2-eq yr^{-1} for the B1 scenario to 482 Mton CO_2-eq yr^{-1} for the A2 scenario. The analysis of the measures showed that the impact of mitigation measures on GHG emissions is much larger than the impact of different financial options in the Common Agricultural Policy. Full implementation of the simulated mitigation measures could lead to a reduction of GHG emissions from agriculture by 127 Mton CO_2-eq yr^{-1}, which is about a quarter of the current GHG emissions from agriculture. Promoting mitigation measures is therefore more effective than influencing income and price subsidies within the CAP to reduce GHG emissions from agriculture.

Appendix. Deliverables for Development of scenarios, mitigation options and databases.

Scientific papers

De Vries, W., J. P. Lesschen, D.A. Oudendag, J. Kros, J.C. Voogd, E. Stehfest and A.F. Bouwman, 2010. Impacts of model structure and data aggregation on European wide predictions of nitrogen and green house gas fluxes in response to changes in live stock, land cover and land management. *Journal of Integrative Environmental Sciences*, Vol. 7, No. S1: 145–157.

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Completed Phd

Neumann, K. (October 2010)
Van Bussel, L. (scheduled end 2011)

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Integration series.

Integration

The question is how to increase the 'adaptive capacity' of our society. Analysis of the adaptive capacity is related to the physical component (the feasibility of physical spatial adaptation) and to the existing institutional structures. Areas Climate changes Spatial Planning dealt with are: uncertainties and perceptions of risk; institutional capacity to deal with climate change; the use of policy instruments; and cost benefit analysis. Adaptation strategies must be in line with the current institutional structures of a policy area. For a proper decision process we developed decision support tools, such as socio-economic scenarios, the Climate Effect Atlas and other assessment frameworks.

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