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Potentials for Greenhouse Gas Mitigation in Agriculture

Review of research findings, options for mitigation and recommendations for development cooperation

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Table of contents

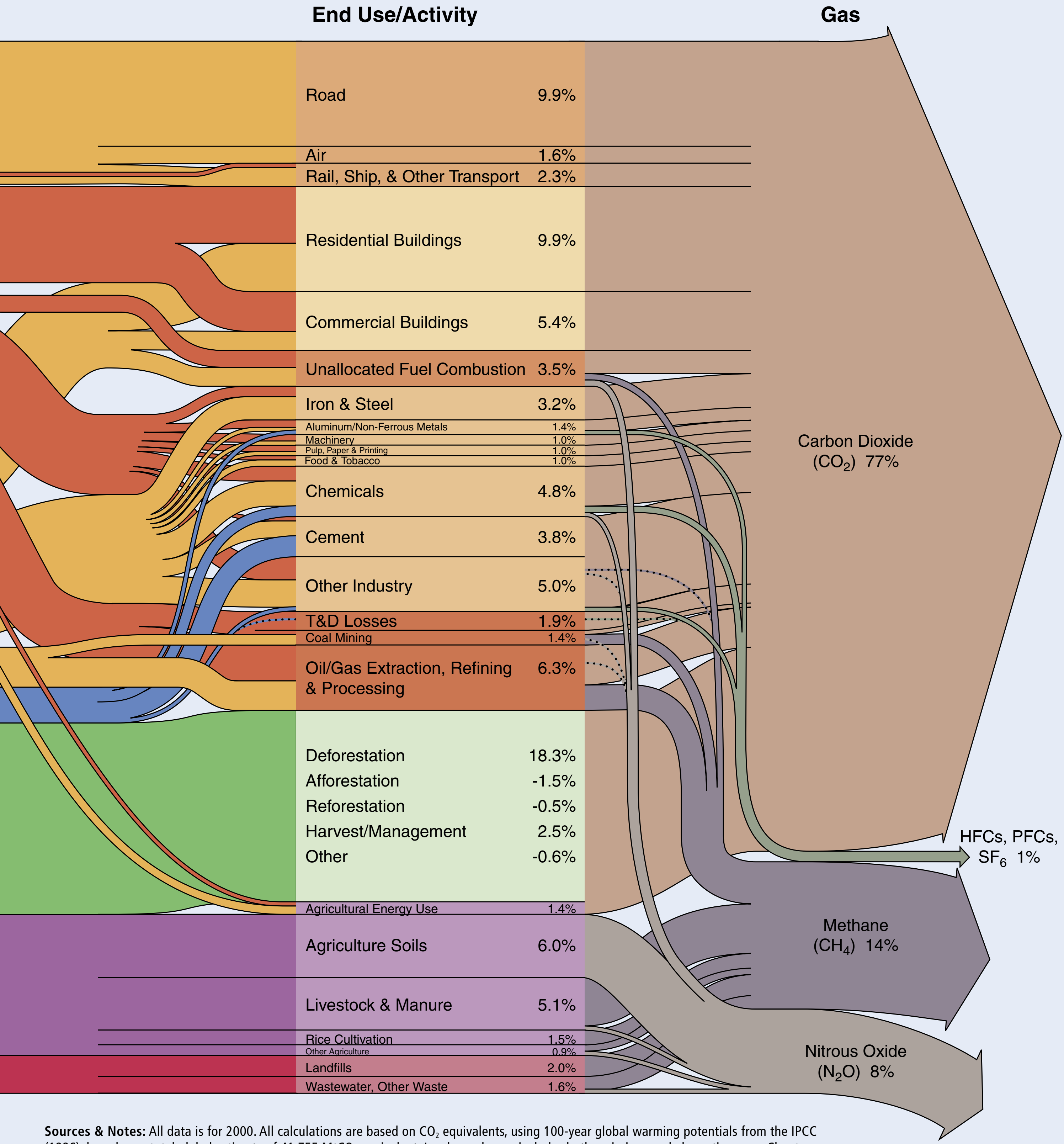
List of figures

List of tables

Abbreviations and acronyms

BMZ .... Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung
CCAFS .... (Research Programme on) Climate Change, Agriculture and Food Security
CDM .... Clean Development Mechanism
CER .... Certified Emission Reduction (units)
CFC .... Chlorofluorocarbon (industrial greenhouse gas)
CGIAR .... Consultative Group on International Agricultural Research
CH_4 .... Methane
CIAT .... International Centre for Tropical Agriculture
CO_2 .... Carbon Dioxide
CO_2-eq .... Carbon Dioxide Equivalents (of other greenhouse gases)
COP .... Conference Of the Parties
CSA .... Climate Smart Agriculture
CSL .... Climate Smart Landscapes
DC .... Developing Countries
EIT .... Economies In Transition
EJ .... Exajoule (energy measurement)
EMP .... Economic Mitigation Potential
FAO .... Food and Agriculture Organization of the United Nations
FAOSTAT .... Statistics Division of the FAO
FPCM .... Fat and Protein Corrected Milk
GHG .... Greenhouse Gas
GIZ .... Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GNI .... Gross National Income
GNP .... Gross National Product
GWP .... Global Warming Potential
gt .... giga ton (1 giga ton corresponds to 1 peta gramm)
IETA .... International Emissions Trading Association
IFA .... International Fertilizer Industry Association
IFAD .... International Fund for Agricultural Development
IPCC .... Intergovernmental Panel on Climate Change
LDCF .... Least Developed Countries Fund
LEDS .... Low Emission Development Strategies
LULUCF .... Land use, land use change & forestry
MAC© .... Marginal Abatement Cost (Curve)
N_2O .... Nitrous oxide
NAMA .... Nationally Appropriate Mitigation Actions
NAPA .... National Adaptation Programmes of Action
NEPAD .... New Partnership for Africa's Development
NGO .... Non-Governmental Organization
OA .... Organic Agriculture
OECD .... Organization for Economic Cooperation and Development
PES .... Payment for Ecosystem Services
ppb .... parts per billion
ppm .... parts per million
pg .... peta gramm (1 giga ton corresponds to 1 peta gramm)
REDD .... Reducing Emissions from Deforestation and forest Degradation
REDD+ .... also includes livelihood needs of the population living in forest areas and the sustainable use of forests allowing carbon sequestration
RCP .... Representative Concentration Pathways
SAMPLES .... Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems
SCCF .... Special Climate Change Fund
SHAMBA .... Small Holder Agriculture Mitigation Benefit Assessment
SHF .... Sulfurhexafluride (industrial greenhouse gas)
SRES .... Special Report on Emission Scenarios
TMP .... Technical Mitigation Potential
UN .... United Nations
UN-CBD .... United Nations – Convention on Biological Diversity
UN-CCD .... United Nations – Convention to Combat Desertification
UNFCCC .... United Nations – Framework Convention on Climate Change
USD .... United States Dollar
US-EPA .... United States – Environmental Protection Agency
WMO .... World Meteorological Organization

Human greenhouse gas emissions according to activities



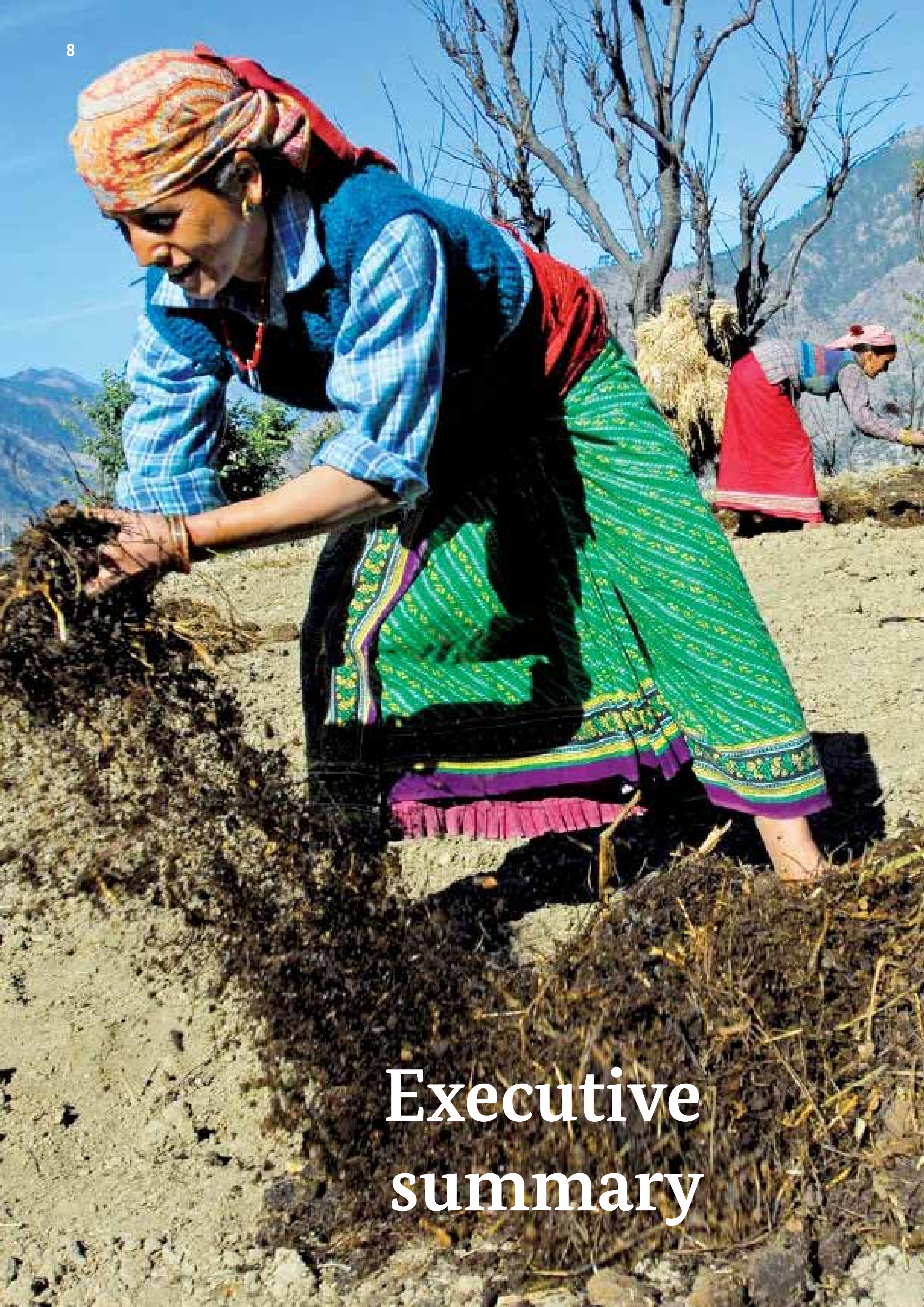
Sources & Notes: All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41,755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions; see Chapter 17. See Appendix 2 for detailed description of sector and end use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

Source: Navigating the Numbers, Baumert et al. 2005

Introductory note

Global warming is steadily increasing and impacting on highly vulnerable developing countries. Most (sub-)tropical areas are expected to suffer from negative impacts on all sectors. Agriculture is as an essential sector for most of these countries with regard to national food security and economy will face considerable yield decreases. Agriculture is both, contributing to climate change with its emissions and suffering from the effects of climate change. Globally, greenhouse gas emissions from agriculture account for about one third of all greenhouse gas emissions. Nevertheless, financial incentives for mitigating emissions from agriculture are rare. Mitigation is generally regarded as a co-benefit of adaptation and up to now, most national and international efforts are spent on climate change adaptation of the sector.

The study has been commissioned by the GIZ sector project Sustainable Agriculture (NAREN), which is funded by the German Ministry for Economic Cooperation and Development (BMZ). On behalf of BMZ it reviews and analyses the currently available information about emissions caused by agriculture and examines potentials of the sector to reduce emissions and to sequester carbon dioxide from the atmosphere. It will contribute to inform the international discussion about the potentials of the agricultural sector and associated land-use change.



Executive summary

GHG emissions in agriculture and land use

Global warming is steadily increasing. Developing countries are vulnerable to its impacts, because of their physical exposure and their high dependency on climate-sensitive natural resources for agriculture. They only have low adaptive capacity because of poverty, weak institutions and limited access to improved adaptation technologies. Most (sub-)tropical areas are expected to suffer from considerable yield decreases, while temperate areas are likely to benefit from yield increases as impacts of climate change. Up to now, most national and international efforts were spent on the development and transfer of climate change adaptation techniques. This review highlights the potentials to reduce greenhouse gas emissions originating from the sectors of agriculture and land use change [1] but also to remove carbon dioxide from the atmosphere through both sectors (sequestration).

Three greenhouse gases (GHG) are relevant for agriculture and land use change: **carbon dioxide** caused by the burning or mineralisation of biomass (e.g. deforestation) and by fossil fuel consumption (machinery), methane produced through enteric fermentation by ruminants, by manure management and in irrigated rice production and, finally, nitrous oxide from use of nitrogenous fertilizer. GHG originating from agriculture contribute at 14 per cent, and from land use change and forestry at 17 per cent to the global GHG emissions, adding to more than 30 per cent in total. Middle-income developing countries release the largest share of GHG related to agriculture and land use change, whereas low-income countries only release a small amount of GHG from these two sectors. The specific GHG sources vary according to the main geographic regions. Nitrous oxide is an important emission source in developing regions of East Asia (China and India). Methane from enteric fermentation of ruminants is especially high in Latin America, while methane from rice production is dominant in the South and East Asian countries.

Nitrogen fertilization contributes substantially to agricultural productivity, but if applied in excess and during inappropriate periods, it releases considerable amounts of particularly harmful nitrous oxide. In Asia, the application of synthetic nitrogen fertilizer is still strongly increasing, partly as a result of national subsidy systems. Moreover, the energy-intensive production of nitrogen fertilizer releases high amounts of carbon dioxide registered in the industrial sector. Organic fertilizers (manure) also accounts for nitrous oxide and methane release if it is not stored, managed and applied appropriately.

Irrigated rice production releases methane to the atmosphere. Water management, especially the shortening of the flooding periods, reduces the release of methane considerably.

Livestock husbandry produces GHG from several sources. Due to increasing meat consumption, livestock husbandry is continuing to increase strongly, especially pigs and poultry production. Therefore, grazing and fodder production areas were increased, often to the expense of forest areas and wetlands in tropical countries such as Brazil and Indonesia. The conversion of forest and wetlands to grazing and fodder production releases huge quantities of carbon dioxide formerly stored in soils and vegetation. In addition, ruminants produce methane through enteric fermentation as further important GHG source originating from livestock. The ratio of GHG per quantity of livestock product released during the lifecycle of animals is higher in arid and semi-arid zones with low productivity than in highly productive livestock systems. However, extensive livestock production is often the most important livelihood option in marginal production areas despite its relatively high methane emissions.

The **utilisation of fuel** for pumped irrigation systems and agricultural machinery, as well as for the production of agrochemicals also has to be taken into account in the overall agricultural GHG balance. **Processing, cooling and storage, transporting and cooking** of agricultural produce also consume energy. Considerable amounts of foodstuffs are wast-

[1] Land use, land use change and forestry as defined by the Intergovernmental Panel on Climate Change

ed during this chain between farmers and consumers. They increase the **lifecycle emissions** and carbon footprint of the produces, as well as the volume of required food to be produced to ensure overall food security. **Biofuels** increase the GHG release from agriculture, while they decrease the GHG balance in other sectors where they replace fossil fuels (transport and energy sectors).

Soil and biomass form huge **carbon stores**. Their storage capacity highly depends on the ecosystem and land use. It is generally high in wetlands, grasslands and forests. Croplands show the lowest carbon concentration (except deserts and semi-deserts), especially if the produced biomass is removed. Land cover, forests and undisturbed wetlands with high carbon storing capacity have dramatically reduced and are further reduced through human land use change and climate change (boreal forests). The converted land often does not serve any more as powerful carbon store.

The **projected scenarios on global warming** expect a temperature increase between 1.8 and 4°C for the present century, depending on the assumed population growth rate, economic growth, technological progress and the extent to which environmental concerns will be taken into account. The growing world population with changing diets, especially increased meat consumption, has unfavourable GHG effects, while technological progress leads to increased agricultural productivity and partly alleviates the GHG balance.

GHG Mitigation options for agriculture and land use

There are **three GHG mitigation options** in agriculture and land-use change & forestry: (i) increasing carbon dioxide storage in soils and biomass, (ii) reducing emissions during agricultural production, and (iii) indirectly, reducing the required volume of agricultural production. Many low-income countries theoretically have a positive GHG balance, since their technical potential for carbon sequestration exceeds the volume of their GHG releases. The challenge of feeding the global population and reducing agricultural GHG emissions requires the successful transfer of climate-friendly agricultural and land use practices to farmers serving adaptation and mitigation needs. It requires an increase of agricultural productivity with a minimum GHG release per product. The reduction of food wastage and the adaptation of more climate-friendly diets can reduce pressure from food production on limited land. Improved family planning to reduce population growth is another important area of action.

The **technically feasible mitigation potential** of agricultural management practices amounts to about 6 giga tons/year of carbon dioxide (equivalents) and could counterbalance the GHG released from either agriculture or from land use change. However, the **economically feasible mitigation potential** is less: at costs of 100 USD per ton of carbon dioxide (equivalents), 73 per cent of this technically feasible mitigation potential could be achieved. At a carbon price of 20 USD per ton, 28 per cent of this potential could be achieved. However, the current carbon price in emission trading schemes is less than 10 USD, which shows the limited mitigation potential that could be feasible through carbon funding. Since international funds for these public climate benefits are not sufficiently available, mitigation measures have to offer other incentives than payment to facilitate their adoption by farmers, such as increases in yield, food security or income. The most efficient mitigation potential is the renouncement to forest and wetland destruction, whereas the restoration of grasslands and degraded lands is considerably more expensive.

Technical progress in agriculture will result in further productivity increases in the future. The rate of productivity increase is however not known. Agricultural productivity can particularly be increased in those mainly temperate areas in the northern hemisphere, where potential yields are higher than those currently achieved. The requirement of cropland for food production reduces accordingly. If these developments occur and opportunity costs for other cropping options are not encountered, **restoring degraded lands** and better managing crop- and grazing land allows considerably improved carbon sequestration.

The technical mitigation techniques in **cropping systems** refer to agronomic practices that allow maximum biomass production on croplands with good soil cover, efficient nutrient management, reduced synthetic nitrogen fertilization, and by caring for optimum growth conditions and carbon sequestration in soils and biomass. These measures highly coincide with climate change adaptation requirements, allowing good synergies for their combined promotion. At farmers level, several adaptation benefits i.e. securing high yields and improving food security and income help promoting the adoption of new techniques.

Livestock and grassland management offer a range of mitigation measures related to improved lifecycle productivity or respecting the specific agronomic site factors when selecting animal species. Reasonable herding with reduced herd sizes and avoiding overgrazing allows grasslands to recover that could be enriched by other root-voluminous crops to maximise carbon storage. Optimum lifecycle management, nutrient cycles and dietary measures can reduce GHG release from livestock raising.

Most of the climate change mitigation measures are at the same time adaptation measures and offer multiple-win opportunities for farmers in developing countries. The **co-benefits** between climate change mitigation and adaptation measures and other environmental policies are much more important than the trade-offs between them. The international conventions on biodiversity, on combatting desertification and on protecting wetlands comprise numerous actions that contribute to climate change adaptation and mitigation at the same time. Nevertheless, policies that emphasize strongly on increases in agricultural production bear a risk of extending agricultural areas and the utilization of excess nitrogen fertilizers while neglecting climate-smart options. The competition with food security objectives will have to be balanced as far as possible.

At the international level, the **concept of climate smart agriculture** concentrates and shapes a number of techniques as elements of already existing agricultural concepts i.e. ecosystem-based approach, eco-agriculture in the light of climate change for both, adaptation and mitigation purposes. It is currently further developed into a more holistic climate smart landscape approach. Other concepts such as organic agriculture also offer good combined adaptation and mitigation solutions. In practice, their mitigation performance compared to conventional production differs according to agro-ecologic factors and farming systems and needs further investigation.

At the international level, the **Kyoto Protocol** defined binding obligations for industrialized countries to reduce their GHG emissions and appeals to developing countries to follow in accordance with their development needs. A complex funding system for adaptation and mitigation has been established. The '**Clean Development Mechanism**' provides the framework for emission trading with developing countries, in which emission reduction often is less expensive. In addition, the 'Reducing Emissions from Deforestation and Forest Degradation' – Program **(REDD+)** intends to positively influence the forest carbon balance through national programs and actions. The **Global Environmental Facility** is operational since many years with funding for a wider scope of environmental concerns and a number of other funding sources are either available or under development. In contrast, the progress in international negotiations and agreements has slowed down.

An increasing number of countries have formulated '**Nationally Appropriate Mitigation Actions**' or '**Low Emission Development Strategies**' out of which a considerable number also identifies actions in the agriculture sector. These plans are often well interlinked with other environmental strategies, but many of them show contradictions with agricultural development plans. The progress of their implementation is generally slow. Mitigation activities are not necessarily linked to these documents.

The 'Consultative Group on International Agricultural Research' with its 'Research Programme on Climate Change, Agriculture and Food Security' coordinates the **international research** with focus on adaptation to climate change, managing climate risk and pro-poor climate change mitigation. The identification of monitoring methods for GHG release in agriculture is under progress.

Conclusions and recommendations

The review shows that the scope of action for climate change mitigation in agriculture worldwide is vast. The focus of action depends on ecosystems, agro-climatic and agro-economic characteristics and livelihoods in the different regions of the world. GHG emissions in agriculture and land use change are mainly emitted in high and middle-income countries, while all groups of countries have a high potential for carbon sequestration.

The international debate on integrating the GHG mitigation of the agricultural sector into global financial compensation mechanisms is progressing slowly. Since mitigation gives only long-term public benefits to society and no tangible individual benefits to farmers who practice them at short term. Therefore, it can only be successfully promoted at farmers level as a co-benefit in combination with climate change adaptation and other environmental policies that offer obvious benefits within a reasonable delay to farmers. In addition, compensation mechanisms will be required on communal lands, and more climate friendly agricultural policies.

Development cooperation can support GHG mitigation through following process and areas of support:

1. analysing of GHG emissions as well as sequestration potentials at country level and identifying the major mitigation potentials;
2. verifying other development policies and their synergies and trade-offs with the mitigation potentials;
3. formulating combined adaptation and mitigation plans at national level and mainstreaming mitigation interests and potentials into other national policies;
4. identifying trade-offs with other policies (agricultural growth and food security) and balancing the competing aspects as far as possible;
5. transferring the national strategies into local and regional conditions with their respective agro-ecological characteristics and livelihood needs;
6. improving capacities of extension services to transfer knowledge and techniques to farmers in the most effective, efficient and sustainable way;
7. identifying gaps, where short term benefits for farmers might not be sufficient to adopt new technologies, especially on communal lands, and search for environmental services payments and their availability at the local level;
8. minimizing post-harvest food losses during harvest, storage, transport, processing, preparation and as food waste;
9. working towards changing human diets that involve less GHG emissions, and
10. foster family planning to reduce future pressure on agricultural land and food production.

The cross-sectoral experience of development cooperation, its long-standing experience in sustainable agricultural and natural resource management concepts could be helpful in many regards.

The international debate is mainly focussing on GHG reduction targets in the industrial and energy sector. Global GHG mitigation and climate friendly global governance in the agricultural and land use sectors have to consider food requirements too. If substantial GHG reduction or carbon sequestration services are desired in developing countries with a high burden of projected productivity loss, a debate on a partial shifting of food production to temperate areas with yield gaps and the compensation of carbon sequestration and food deficits for the developing countries should also be launched.

1 Background

Global warming is steadily increasing. Developing countries are vulnerable to its impacts, because of their physical exposure and their high dependency on climate-sensitive natural resources for agriculture. They only have low adaptive capacity because of poverty, weak institutions and limited access to improved adaptation technologies. Most (sub-)tropical areas are expected to suffer from considerable yield decreases, while temperate areas are likely to benefit from yield increases as impacts of climate change. Up to now, most national and international efforts were spent on the development and transfer of climate change adaptation techniques. This review highlights the potentials to reduce greenhouse gas emissions originating from the sectors of agriculture and land use change [2] but also to remove carbon dioxide from the atmosphere through both sectors (sequestration).

The threat of global warming has increased. Environmental impacts connected to climate change are occurring at rates faster than initially projected. Dramatic and rapid reductions of arctic sea ice have been recorded in September 2012 with up to 49 per cent less ice than the long-term average. The latest report of the Intergovernmental Panel on Climate Change (IPCC 2013) mentions that the temperature of the upper part of oceans and air temperature in some regions have particularly increased. In consequence, the sea level rose by 0.19 m between 1901 and 2010. During the last decade, the global mean sea level has even risen by 3.2 mm/year. There is widespread acknowledgement of extreme weather events due to climate change, such as the frequency of heavy precipitation, storms, and heat waves. At the same time, atmospheric greenhouse gas (GHG) concentrations continue to increase. Agriculture contributes with up to 15 per cent directly to these GHG emissions, mainly through the release of methane and nitrous oxides. In addition, agriculture is the most important driving factor of land use change i.e. the transformation of forested and range lands into croplands, which contributes with another 17 per cent to the global GHG emissions (land use, land use change & forestry), mainly as carbon dioxide.

Developing countries are severely threatened and vulnerable to climate change. They are often localized in regions heavily affected by climate change (exposure), such as in low-lying river deltas, which are easily affected by climate change related weather events (high sensitivity). Livelihoods in these countries largely depend on climate-sensitive natural resources. At the same time, national institutions and the people have insufficient means to manage the corresponding risks (low adaptive capacity). Estimates state that developing countries will bear 75 to 80 per cent of the costs of damages caused by climate change. Even 2°C of global warming above pre-industrial temperatures (the minimum projected and envisaged for the 21st century) could result in permanent reductions of the gross national product of Africa and South Asia of 4 to 5 per cent. These trends and forecasts may require revision since recent outlooks show that the 4°C temperature threshold may be exceeded before the end of this century (World Bank 2012).

'Climate change is costly, whatever policy is chosen: spending less on mitigation will mean spending more on adaptation and accepting greater damages, while the cost of action must be compared with the cost of inaction' (World Bank 2010). This is even more valid when threats to poverty reduction and food security are considered: nourishing the projected nine billion people by 2050 will require strong measures to intensify production systems on limited land areas without additional land clearing and land degradation. Therefore, degraded land needs to be rehabilitated for agriculture and increased environmental services like the sequestration of carbon from the atmosphere.

The GHG originating from agriculture have increased by 17 per cent between 1990 and 2005, including an increase of 32 per cent in developing countries, and a decrease of 12 per cent in developed countries (Smith 2007). Thus, the reduction of emissions by agriculture in developed countries alone

[2] Land use, land use change and forestry as defined by the Intergovernmental Panel on Climate Change

will not be enough to limit contribution of the sector to global warming. Emissions have particularly caught up in middle-income countries. Concerning emissions from land-use change, by far the largest share of current emissions comes from tropical countries in developing regions.

It is imperative to note that despite such a critical outlook, diverse opportunities, especially concerning carbon sequestration by optimized land use, are available to reduce and counterbalance GHG emissions, and have yet to be taken advantage of. Land use change in developing countries constitutes the biggest driver of GHG, especially where forest resources are converted into arable land and grasslands. The separation of agriculture and land use, land use change & forestry as two sectors within the existing definition of global GHG categories does not foster comprehensive analysis and action. This separation is more and more overcome by recent studies that combine and interconnect both sectors.

Considerable efforts on climate change adaptation in agriculture have been undertaken to reduce vulnerability of people in developing countries. National action plans and strategies for adaptation have been designed in many countries. However, up to now, only few explicit efforts have focused on positively influencing the GHG balance of the agricultural sector. Climate change mitigation involves two response strategies:

i) reducing the amount of emissions (abatement), and
ii) enhancing the absorption of carbon dioxide through vegetation and soils (sequestration).

This unique second option gives agriculture and land use a prominent mitigation role, since carbon dioxide produced in other sectors (industry, transport, energy) can be absorbed.

The first meaningful discussions on the contribution of agriculture to the resolution of the global climatic crisis have been carried out in Copenhagen in 2009.

These discussions are on-going. In fact, views are controversial on the inclusion of agriculture into financial compensation mechanisms as in the forestry sector, where the mechanism of Reducing Emissions from Deforestation and Forest Degradation (REDD) in 2007 (and REDD+ [3] since 2010) is implemented.

The mitigation potential can be assessed under technical and economic aspects. The theoretic technical mitigation potential through carbon fixing in the agriculture and land use change sectors is similar to the GHG emissions from agriculture. Thus, the overall GHG balance in agriculture and land use could be neutral. Some of the mitigation opportunities also offer an increased income for farmers and are, therefore, likely to be adopted. Implementing this theoretic technical mitigation potential requires the introduction of mitigation measures, which are partly costly. Therefore, the economic mitigation potential has also to be taken into account. The economic mitigation potential is expressed in carbon prices, which describe the costs for the respective technology change to achieve the technical mitigation potential. The adoption of climate friendly agricultural practices will also rely on appropriate policies and institutions with sufficient outreach in rural areas for their promotion. Thus, there will be additional transaction costs and constraints. As long as carbon prices remain too low to provide sufficient incentive for change, the realisation of mitigation strategies is constricted. This is currently demonstrated by the stagnant REDD mechanism, which does not provide sufficient incentives for forest protection. Carbon markets and compensation mechanisms for the agricultural sector involve important difficulties with regard to implementation and monitoring.

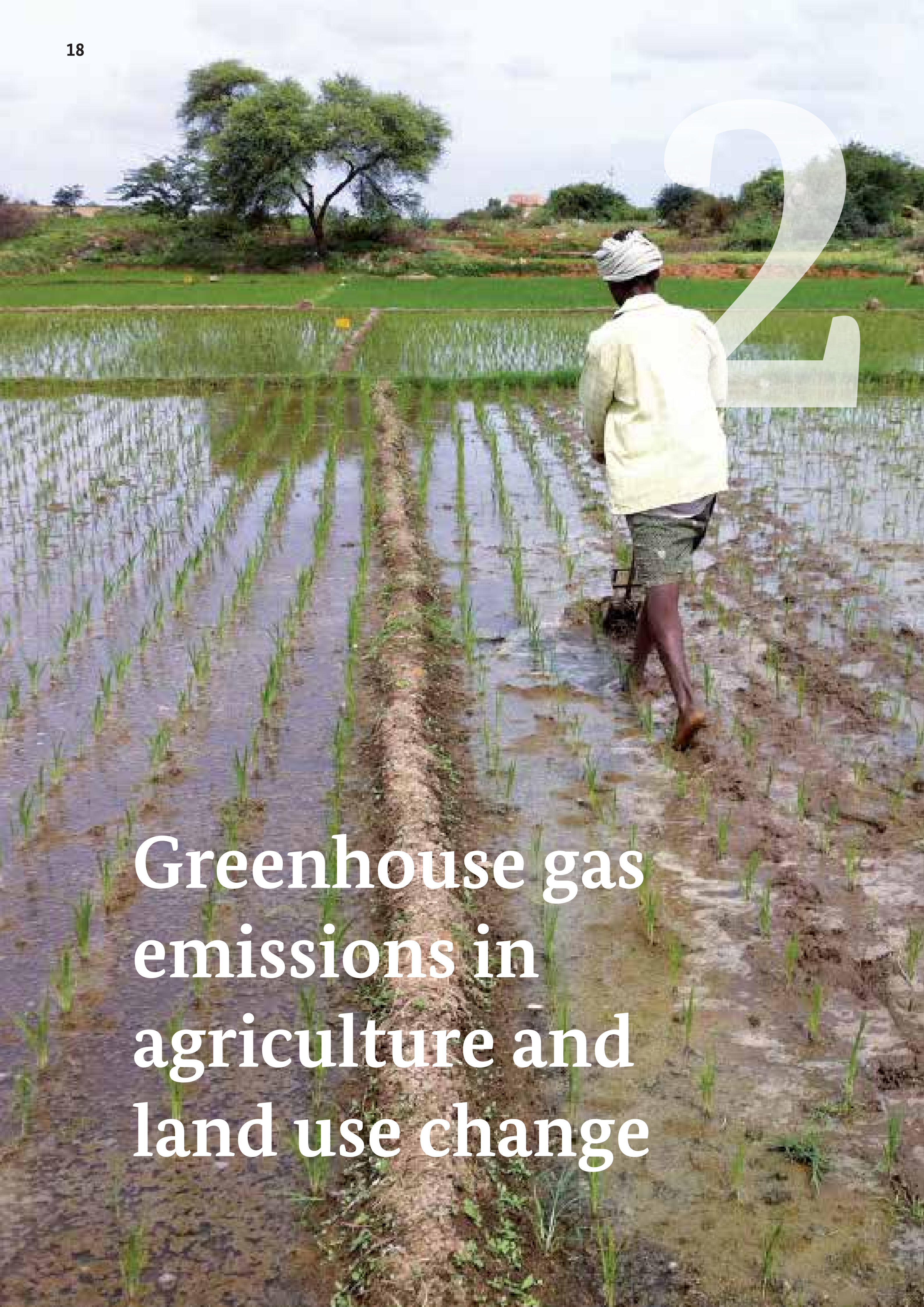
[3] REDD is a financial compensation mechanism to reduce GHG emissions from deforestation and forest degradation through a performance based financial compensation system between GHG emitters and forest protection initiatives (national governments or local organisations). REDD+ also includes livelihood needs of the population living in forest areas and the sustainable use of forests allowing carbon sequestration.

They have to address a high number of stakeholders in rural areas and provide suitable monitoring methods and information. Currently, efforts are underway to close data gaps and develop monitoring options.

There are a number of ways to countervail the incidence of the frightening GHG scenarios drafted by the IPPC, e.g. through appropriate environmental policies and framework conditions to promote technological progress. At present, the technical concept of 'climate-smart agriculture' of the Food and Agriculture Organization (FAO) is promoted by various organizations and has been developed into a landscape approach beyond farmer's level. Climate smart agriculture includes resilience to climate change, sustainable productivity, nutritional quality, and other factors relevant for adaptation and mitigation.

The present review addresses direct emissions from agriculture and land use change as well as indirect emissions connected to agriculture, but accounted in other sectors (transport and industry). It describes mitigation opportunities with a focus on developing countries and traces mitigation options for development cooperation. It is based on a systematic research of data and documents available on the websites of relevant international institutions and organisations. Much of the data refers to global studies carried out between 2000 and 2010. Ascertained subsequent research findings are included, especially on mitigation techniques. New globally aggregated sectoral data for agriculture and land use change is expected from the next report of the sectoral working group (III) of the Intergovernmental Panel on Climate Change (IPCC) in 2014.

Chapter 2 describes the GHG sources and their context. Chapter 3 highlights mitigation potentials. Chapter 4 provides recommendations on the scope of action.



2

Greenhouse gas emissions in agriculture and land use change

2.1 General overview and main trends

Three greenhouse gases (GHG) are relevant for agriculture and land use change: carbon dioxide caused by the burning or mineralisation of biomass (e.g. deforestation) and by fossil fuel consumption (machinery), methane produced through enteric fermentation by ruminants, by manure management and in irrigated rice production and, finally, nitrous oxide from use of nitrogenous fertilizer. GHG originating from agriculture contribute at 14 per cent, and from land use change and forestry at 17 per cent to the global GHG emissions. Middle-income developing countries release the largest share of GHG related to agriculture and land use change, whereas low-income countries only release a small amount of GHG from these two sectors. The specific GHG sources vary according to the main geographic regions. Nitrous oxide is an important emission source in developing regions of East Asia (China and India). Methane from enteric fermentation of ruminants is especially high in Latin America, while methane from rice production is dominant in the South and East Asian countries.

All relevant GHGs originating from agriculture and land use change (carbon dioxide, methane and nitrous oxide) form natural components of the atmosphere. Their global abundance, origins, historical evolution, and their contributions to radiative forcing[4] are shown in table 1.[5]

[4] 'Radiative Forcing' measures the difference of radiant energy received by the earth and energy radiated back to space and describes the GHG warming potential in addition to the natural emissions that already existed in the pre-industrial period.

[5] Other greenhouse gases included in the Kyoto-Protocol are chlorofluorocarbon (CFC) and sulfur hexafluoride, which however are not important in the agricultural sector.

Table 1 Global abundance of key greenhouse gases in 2011 – evolution and importance

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)
Main origins	Fossil fuels (coal, oil, gas) Burning of biomass (slash and burn, wood) Mineralization of soil organic matter (humus) Deforestation Other land use change	Livestock (ruminants) Irrigated rice Garbage disposal and treatment	Oceans Biomass burning Fertilizer use Industrial processes
Global concentration in the atmosphere in 2011	391 ppm	1,813 ppb	324 ppb
Pre-industrial level in 1750	280 ppm	700 ppb	270 ppb
Increase since 1750	140 % (85 % last decade)	259 %	120 %
Mean annual increase during last 10 years	2.0 ppm/year	3.2 ppb/year	0.78 ppb/year
Contribution to radiative forcing relative to 1750	+ 1.8 W/m^2	+ 0.51 W/m^2	+ 0.18 W/m^2
Total in CO_2-eq mole fraction (ppm)	391	45	97

Source: adjusted from WMO Global Atmosphere Watch, Greenhouse Gas Bulletin no. 8, November 2012

The Global Warming Potential (GWP) of these GHG differs largely with methane (CH_4) having 25 times more GWP and nitrous oxide (N_2O) having 298 times more GWP compared to carbon dioxide (CO_2)[6]. Methane and nitrous oxide are taken into account as equivalents (eq) of CO_2. All three gases have increased during the last decades, and total radiative forcing has augmented by 30 per cent between 1990 and 2011 (WMO 2012).

- Carbon dioxide (CO_2) is a natural component of the atmosphere. Especially the burning of fossil fuels (e.g. transport, industry, heating, etc.) releases critical quantities of CO_2 to the environment. CO_2 also originates from microbial decay, burning of plant residues, and mineralization of soil organic matter (soil humus) – all of which occur in land use change, deforestation, and through slash and burn agriculture.
- Methane (CH_4) results from the decomposition of organic materials under anaerobic conditions (e.g. ruminant digestive system fermentation, manure and production of irrigated rice). It also originates from garbage disposal.
- Nitrous oxide (N_2O) is released into the atmosphere through the utilization of nitrogen fertilizers, soil microbial activity (denitrification), biomass burning and manure. Some industrial processes also produce nitrous oxide.

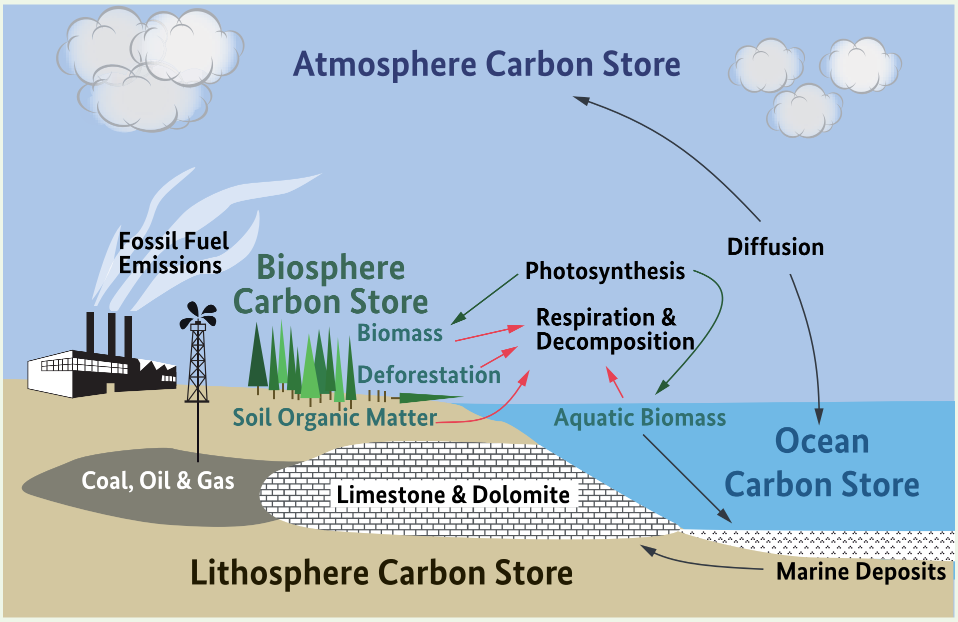
Figure 1 shows the global carbon stores that are subdivided into the atmospheric carbon store, the biosphere, the lithosphere and the ocean carbon store. The focal carbon store in the context of climate change in agriculture is the biosphere carbon store. This carbon store is subdivided into two different pools: the soil carbon pool with its organic and inorganic components, and the biotic carbon pool, including carbon stored in vegetation. There is an intense exchange between the biotic carbon pool and the atmospheric carbon store that is highly influenced by land-use practices. The two other stores (ocean and lithosphere) contain high amounts of immobile carbon.

The IPCC divides GHG emissions into seven sectors (see figure 2). At the global level power and industry are the most important emission sources followed by land-use change and agriculture.

The release of emissions largely differs throughout the world according to income level of countries (see

[6] The comparison refers to a period of 100 years.

Figure 1 **Global carbon cycle and carbon stores**



Source: PhysicalGeography.net / www.camelclimatechange.org figure 3). If all GHG origins are considered [7], middle-income countries, contribute most to global emissions. They also represent the vast majority of the world's population [8]. In these countries agriculture and land-use change has a high share of 37 per cent of total emissions. A considerable part of the global GHG is released in industrialized countries – but only 8 per cent originate from agriculture here, and without net land use emissions while forest areas have not diminished, but partly augmented here. The limited number of 36 low-income countries represents only a tiny share of global emissions, in which however 70 per cent of GHG derive from agriculture and land use change [9].

The two sectors included in the following analysis are 'agriculture' and 'Land-Use, Land-use Change & Forestry (LULUCF)', focusing on land use change related to agriculture, and referred to as 'land use change' in the following for GHG emissions from this sector. These two sectors account together for 31 per cent of the global GHG emissions.

Most GHG from agriculture (see figure 4) originate from soils and the fermentation process in the stomachs of ruminants (cattle, sheep, goats etc.). Irrigated rice, manure and energy use contribute less to global GHG emissions but can nevertheless be important sources in individual countries.

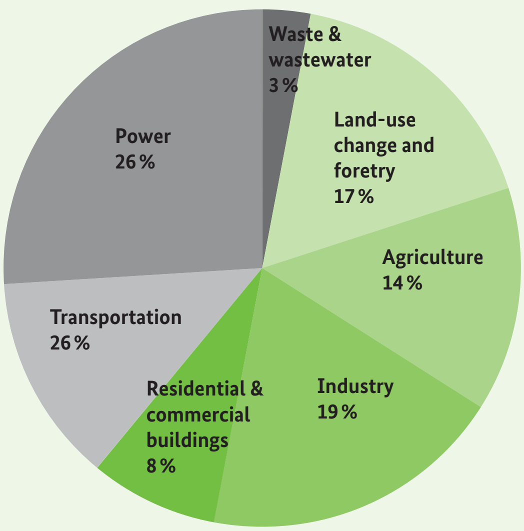
[7] The waste sector incl. solvent and other product use is excluded here (i.e. industrial gases such as CFC and SHF).

[8] 103 middle-income countries with a Gross National Income (GNI) of 1,036 USD – 12,615 USD/capita/year including China and India (World Bank Atlas Method Classification), 36 low-income countries with 1,035 USD/capita/year and 75 high-income countries with 12,616 USD/capita/year.

[9] If per capita release of GHG is considered, the situation changes considerably.

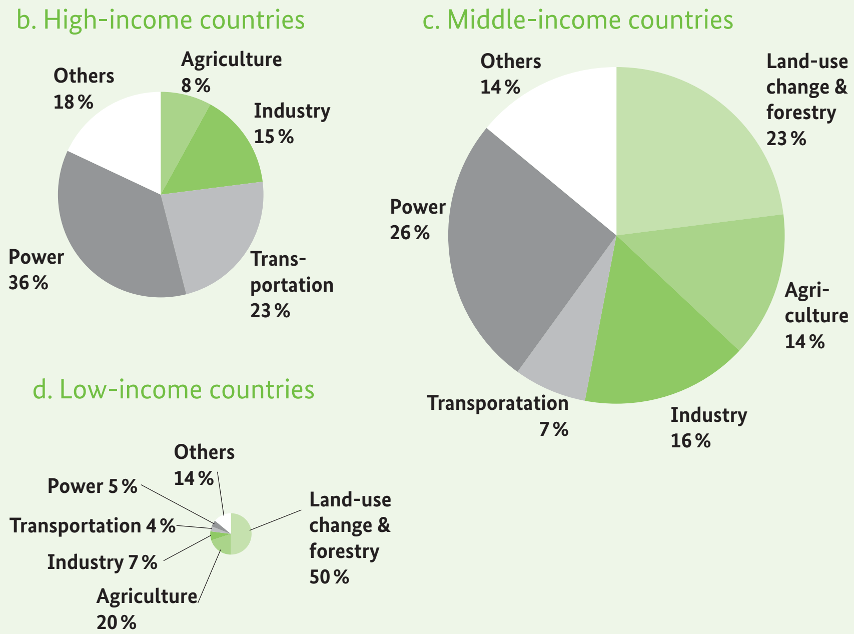
Figure 2 **Global GHG-emissions by sector**

a. World



Source: IPCC 2007 / World Bank 2010

Figure 3 **GHG emissions by sector in high-, middle- and low-income countries**



Source: adapted from World Bank 2010 / Barker et al. 2007

The GHG contributions of the agricultural sector mainly consist of methane and nitrous oxide. Despite the small absolute quantities, which are emitted, they are far more harmful in their climate effects than carbon dioxide. When considering only the agricultural sector, its CO_2 emissions are minor or show even net removals of carbon because of carbon sequestration in most countries except for Eastern Europe and Central Asia (US-EPA 2006, Bellarby et al. 2008).

In contrast to CO_2 emissions, methane and nitrous oxide emissions from agriculture have globally increased by nearly 17 per cent between 1990 and 2005 (Smith et al. 2007) with a 32 per cent increase in developing countries. Conversely, developed countries showed a 12 per cent decrease [10] during the same period. At a global level, the release of both gases is expected to further increase in the future.

In addition to the 5,621 million tons (15 per cent) of CO_2-eq produced by the agricultural sector and the 5,900 million tons CO_2-eq (17 per cent) of land use change & forestry, another 1,009 million tons CO_2-eq are produced by fertilizer and pesticide producing industry, pumping and farm machinery and can be indirectly attributed to agriculture (see table 2). Many data remain as estimates due to uncertainties and non-agreed aspects. The estimates between different sources differ, e.g. between 10 to 15 per cent share of GHG from agriculture.

[10] Europe and Russia had considerable decreases, while the US and Canada showed increases.

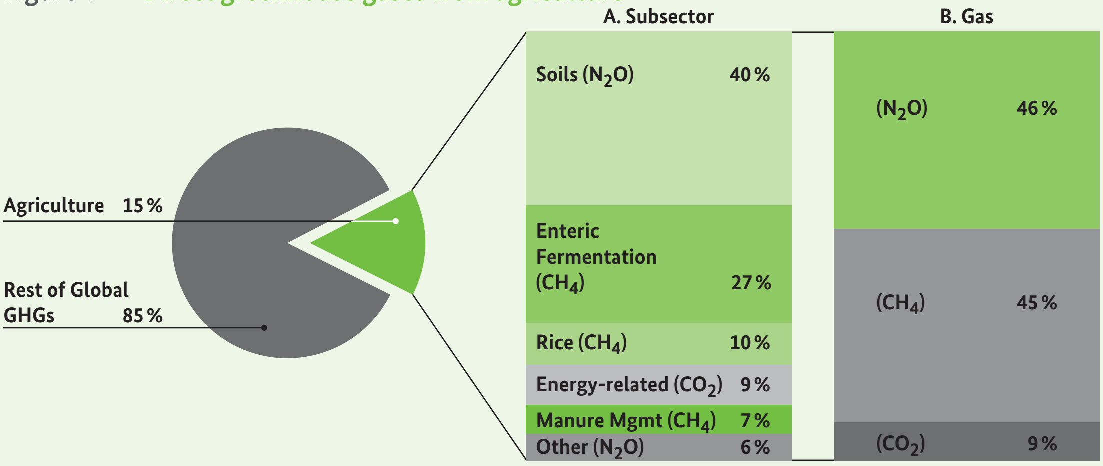
The composition and evolution of GHG emissions differ according to world regions and ask for specific mitigation strategies. Figure 5 shows the evolution and projection of the two most important agricultural GHGs (nitrous oxide and methane emissions) for the developing regions. Projections estimate the increase of agricultural GHG (N_2O and CH_4) at about 13 per cent between 2010 and 2020, and at 10 to 15 per cent for the period between 2020 and 2030. However, a stagnation or decline of agricultural GHG after 2030 may be due to reduced increase of cropping area (and deforestation), the application of conservation tillage practices, but also to technological advances (Smith et al. 2007).

All regions showed increasing emissions for these two most important GHGs for the past as well as future trends. Africa and Latin America exhibit the highest increases since 1990. A full scenario for all regions is found in annex 3.1.

It becomes obvious that the amount and composition of GHG is specific for each regions with the following main disparities:

- Nitrogen losses from soils are an important emission source in all regions and offer opportunities to reduce emissions while improving soil fertility.
- Methane release from irrigated rice production release is important in East Asia and South Asia.
- The burning of biomass is widespread in Latin America and Sub-Saharan Africa.
- Enteric fermentation is an important GHG source in all regions but most important in Latin America with its high ruminant concentration and extended rangelands.

Figure 4 **Direct greenhouse gases from agriculture**



Sources & Notes: adapted from EPA, 2004. See Appendix 2.A for data sources Appendix 2.B for sector definition. Absolute emissions in this sector, estimated here for 2000, are 6,205 $MtCO_2$. Source: Baumert et al. 2005

Table 2 Composition of GHG – direct and indirect relation to agriculture

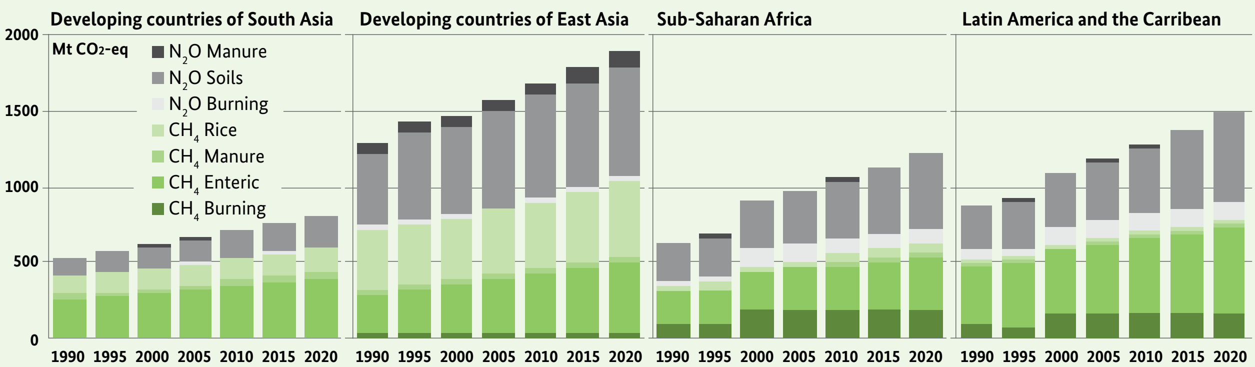
Sector	Categories related to agriculture	Category of GHG	Contribution	
			Million tons CO_2-eq	Relative
Agriculture	Enteric fermentation in ruminants	Methane	(cattle) 1,792	32 %
	Livestock manure management	Methane	413	7 %
	Flooded rice production	Methane	616	10 %
	Fertilization of agricultural soils	Nitrous oxide	2,128	38 %
	Field burning of biomass waste and burning of savannahs for crop management purposes	Carbon dioxide	672	12 %
Sub-Total: Agriculture 15 % (10 – 15 % estimates)			5,621	100 %
Land use, land use change & forestry, (LULUCF)	Conversion of forest into agricultural land	Carbon dioxide	5,900	
	Land use change	Carbon dioxide		
Sub-Total Land use change: 17 %			5,900	
Industry	Production of fertilizers	Carbon dioxide	410	
	Production of pesticides	Nitrous oxide	72	
Energy consumption	Agricultural farm machinery	Carbon dioxide	158	
	Irrigation (pumping)	Carbon dioxide	369	
Sub-Total from other sectors			1,009	
Total			**12,530**	

Sources: Various, incl. Baumert et al. (2005), Smith et al. (2007), Bellarby et al. (2008), Gattinger et al. (2011)

CO_2 emissions from land use change are concentrated in countries experiencing severe deforestation primarily as a result of economic prospects. Examples of such market-oriented deforestation are common in Brazil to extend grazing, fodder and soybean production to meet the increased meat demand. Indonesia carries out large-scale conversion of forests to palm oil plantations and Liberia also poses extreme cases of deforestation for palm oil production. These activities destroy carbon sinks and biodiversity, often in the absence of efficient forest protection.

Developing countries are vulnerable to climate change for diverse reasons. Regarding the impact of climate change on the yield of major crops, the temperate regions, mainly in the northern hemisphere, will benefit from increased productivity (see figure 6). In contrast, countries in sub-tropical and tropical areas and Australia, will suffer from considerable productivity losses. The developing countries in these regions may not be able to contribute much to mitigation, since their potential – especially for sequestration – is declining due to higher tempera-

Figure 5 Estimated historical and projected N_2O and CH_4 emissions in the agricultural sector of developing regions during the period 1990 – 2020



Source: adapted from Smith et al. 2007, page 504 (adapted from US-EPA 2006) tures increasing soil humus mineralization, unreliable rainfall reducing growth of the vegetation and overall desertification. Additionally, many of these countries do neither have the institutional capacity nor the financial means to implement mitigation measures.

2.2 Nitrogen fertilization

Nitrogen fertilization contributes substantially to agricultural productivity, but if applied in excess and during inappropriate periods, it releases considerable amounts of particularly harmful nitrous oxide. In Asia, the application of synthetic nitrogen fertilizer is still strongly increasing, partly as a result of subsidies. Moreover, the energy-intensive production of nitrogen fertilizer releases high amounts of carbon dioxide registered in the industrial sector. Organic fertilizers (manure) also accounts for nitrous oxide and methane release if it is not stored, managed and applied appropriately.

While soil fertilization with nitrogen (esp. synthetic) has substantially contributed to agricultural productivity increases during the last decades, it also causes harmful GHG emissions. Nitrogen fertilization, through either mineral fertilizers or organic manure from livestock or compost, releases considerable amounts of nitrous oxide. N_2O is harmful even in small quantities due to its high GWP (298 times more than CO_2) and its long persistence in the atmosphere of about 120 years. The burning of biomass e.g. in slash and burn agriculture also results in the release of both, nitrous oxide and methane. About 70 per cent of nitrous oxide originating from human activity results from agriculture.

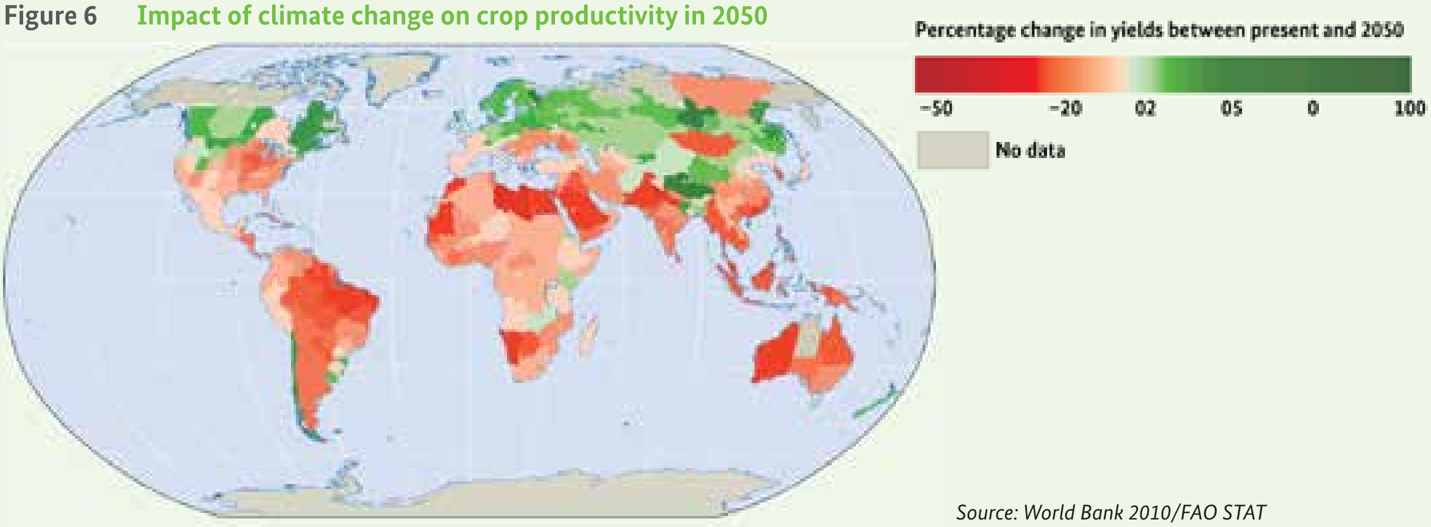
Globally, nitrous oxide is the main source of agricultural GHGs (see figure 4). The area that receives synthetic fertilizers and manure production has strongly increased and manure and synthetic fertilizer application is projected to further increase by 35 to 60 per cent between 2003 and 2030 (FAO 2003). Different scenarios on food demand and changes of human diet cause the high range of this projection. The growing demand for livestock feed has also increased the use of synthetic fertilizers for pastures and fodder crops, and increased livestock populations produce high amounts of manure, which is generally helpful for soil fertility and crop productivity, but harmful if applied in excessive quantities and with inadequate timing.

The extent to which soil is saturated with nitrogen (via the use of synthetic and organic fertilizers) accounts for the degree of nitrous oxide release. Soils with a high nitrogen status emit greater amounts of nitrous oxide. In such soils, a reduced nitrogen supply reduces GHG emissions. Soils with nitrogen deficiency tend to release carbon dioxide, but are likely to react positively with reduced emissions on reasonable nitrogen supply.

2.2.1 Synthetic nitrogen fertilizers

Total nitrogen fertilizer use but also its use per area of pasture and farmland, are steadily increasing (see figure 7). In Europe, nitrogen fertilizer use (synthetic but especially from manure) has decreased since

Figure 6 Impact of climate change on crop productivity in 2050



Source: World Bank 2010/FAO STAT

1995 due to environmental legislation (Nitrate Directive in 1991). In Eastern Europe and Central Asia, the decrease of fertilizer use is mainly connected to the lack of capital for their procurement after the end of the Soviet Union. Statistics from the International Fertilizer Association (IFA) show that China and India consume together 60 per cent of the nitrogen fertilizers used in developing countries. In China, nitrogen and fertilizer subsidy politics contributed much to the sharp increase. Half of the world's nitrogen is used for cereals (IFA 2013).

Africa only uses 2 per cent of nitrogen fertilizers produced and is not included in the graphs of figure 7. South America with considerable fertilizer consumption is not included as well. Here the nitrogen supply to soils is, on average, insufficient to maintain soil fertility, resulting in nutrient depletion and loss of soil organic matter in scarcely or unfertilized soils (Bellarby et al. 2008).

The efficiency of nitrogen utilization in crop production is rather limited with only about 50 per cent de facto incorporation by crops. The remaining 50 percent have deteriorating effects on ecosystems since they are mainly released as N_2O (Steinfeld et al. 2006) or washed into deeper soil layers and the groundwater. Many countries subsidize synthetic fertilizers to boost agricultural productivity and promote their utilization (e.g. China) but not necessarily their efficient application. The amount of volatile nitrogen resulting from synthetic fertilizer depends on the type of fertilizer and increases with temperature. Urea and ammonium bicarbonate fertilizers are specifically volatile. Nonetheless, they are mainly used in developing countries despite higher temperatures. Fertilizers based on anhydrous ammonium nitrogen or ammonium sulphate liberate less N_2O and are therefore more suited for fertilization.

Not only the utilization of synthetic nitrogen fertilizers, but also their production, contributes to the release of GHG, which is estimated at 1.2 per cent of the total world GHG emissions (Bellarby et al. 2008, Wood and Cowie 2004). The production of fertilizer consumes fossil fuel. The emissions are however accounted in the industry sector, but not in the agricultural sector (see also table 2).

2.2.2 Organic fertilizers (manure)

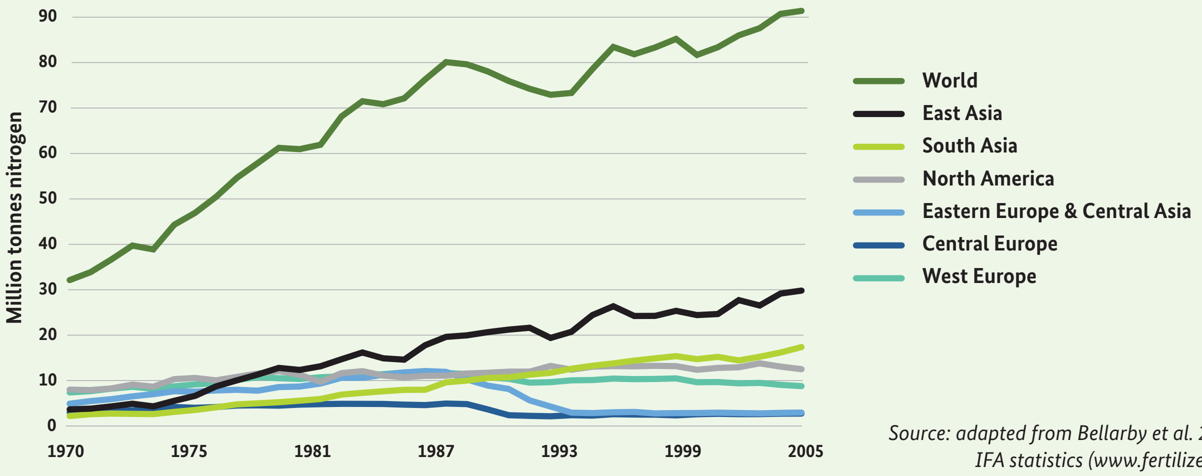
Organic fertilizers (manure) include green manure (plant residues) as well as manure originating from animals, either as excreta that are directly deposited on grasslands (grazing systems) or as managed excreta on farms. Manure contributes to GHG as nitrous oxide resulting from the disposal, storing, and spreading of manure, but also as methane resulting from the anaerobic decomposition of manure (details in annex 3.2). In total, ruminants (especially cattle) contribute to 79 per cent to these nitrous oxide emissions[11]. Industrial production systems are less harmful, because manure here can be managed appropriately, whereas it decomposes on site in extensive grazing systems with nitrous oxide release.

2.2.3 Other emissions from organic fertilizers (methane and carbon dioxide)

The anaerobic decomposition of organic material in livestock manure releases methane, especial-

[11] Pigs contribute with 12 per cent and poultry with about 10 per cent to the total nitrous oxide emissions from animal excreta.

Figure 7 World nitrogen fertilizer consumption according to regions



Source: adapted from Bellarby et al. 2008/ IFA statistics (www.fertilizer.org) ly if manure is managed in the liquid form, while dry manure does not produce significant amounts of methane. The emissions depend on a number of factors that influence the growth of bacteria responsible for methane production (e.g. temperature, moisture, storage time, etc.), but also on the energy content of manure, which directly depends on livestock diet (Steinfeld et al. 2006). Most methane is derived from pig farms (47.8 per cent), closely followed by cattle (42.8 per cent). Intensive industrial pig production releases particularly high emissions (e.g. in China, North America, and Western Europe). In these regions, intensive and large production units with high transport costs for manure management operate in favour of less heavy, but yet more emission producing liquid manure management. The production of biofuels from manure represents an appropriate option to use the methane produced in these intensive livestock farming systems. Substantial amounts of methane also originate from mixed livestock production systems in developing regions (see annex 3.2).

The application of organic fertilizers – usually advantageous for soil fertility management and the environment and therefore known as a good practice – does not necessarily show a neutral carbon balance (Kutsch et al. 2010).

The burning of biomass – considered by farmers as organic fertilization by quick mineralisation – also accounts for methane and carbon dioxide release. It is mainly practiced in Sub-Saharan Africa, Latin America, and the Caribbean (Bellarby et al. 2008). In addition to the GHG emissions, it contributes to soil degradation in terms of soil structure and nutrients, and should be avoided.

2.3 Rice production

> Irrigated rice production releases methane to the atmosphere. Water management, especially the shortening of the flooding periods, reduces the release of methane considerably.

Methane from rice production is released during inundation periods via diffusive transport through the aerenchyma system[12] of rice plants, via ebullition of methane at the water surface, or by leaching methane to ground water. Emissions from irrigated rice are highly concentrated in developing countries - mainly in Asia (97 per cent), where most irrigated rice is produced. In main rice producing countries methane emissions from rice represent an important share of total GHG emissions, e.g. in India, where rice production contributed 9.8 per cent to total GHG emissions in 2006 (IPCC 2007). According to the global trends reported by FAO (2003), rice production areas are expected to increase by only 4.5 per cent between 2003 and 2030.

The extent of rice grown under continuous flooding determines the future increase of methane emissions. The maximum increase is projected at 16 per cent between 2005 and 2020 (US-EPA 2006). Such increase may not be reached due to water scarcity that limits irrigated rice production, while water saving techniques (i.e. alternate drying and wetting, system of rice intensification) or adoption of new cultivars that emit less methane might contribute to reduce methane release in existing flooded rice production areas. Methane emissions from rice production depend on a variety of factors connected to:

- water management (shortening of the flooding periods) as the main factor, and
- rice cultivars and varieties with reduced methane release.

In addition, the release of methane also depends on soil characteristics, crop management and fertilizing practices, e.g. early transplanting of rice crops, optimum soil and nutrient conditions (Gattinger et al 2011). Nitrogen fertilizing causes, in addition, considerable nitrous oxide releases. The System of Rice Intensification (SRI) proves to emit up to 22 per cent less methane than conventional rice production (Nguyen et al. 2008, Proyuth et al. 2012).

Significant methane emissions are only caused by irrigated rice. The emissions from upland rice, representing approximately 15 per cent of the total rice cropping area, is connected to the burning of biomass (slash and burn), often forest areas and results in high CO_2 emissions.

[12] Air transport channelling system in rice roots

2.4 Livestock husbandry

Livestock husbandry produces GHG from several sources. Due to increasing meat consumption, livestock husbandry is continuing to increase strongly, especially pigs and poultry production. Therefore, grazing and fodder production areas were increased, often to the expense of forest areas and wetlands in tropical countries such as Brazil and Indonesia. The conversion of forest and wetlands to grazing and fodder production releases considerable quantities of carbon dioxide formerly stored in soils and vegetation. In addition, ruminants produce methane through enteric fermentation as further important GHG source originating from livestock. The ratio of GHG per quantity of livestock product released during the lifecycle of animals is higher in arid and semiarid zones with low productivity than in highly productive livestock systems. However, extensive livestock production is often the most important livelihood option in marginal production areas despite its relatively high methane emissions.

The 'Livestock's long shadow' report of the FAO on environmental issues and options for livestock husbandry (Steinfeld et al. 2006) caused considerable commotion and concern. Its analysis took all environmental aspects connected to livestock husbandry into account. It attributed 18 per cent of global GHG emissions to the livestock sector comprising 9 per cent of CO_2-eq as methane from enteric fermentation and 9 per cent of CO_2 for land use change connected to livestock husbandry. This alarming figure was downsized to 15 per cent, by subsequent studies, but even a 15 per cent GHG share is alarming and gives important potential for mitigation. The share of GHG related to former forested areas converted into pastures differs significantly between regions and is particularly high in South East Asia and South America.

The livestock sector occupies 70 to 75 per cent of the total agricultural land, and about 35 per cent of all cropland. The total anthropogenic biomass appropriation, which is directly consumed by humans, is about 62 per cent, while 35 per cent of the biomass is used for animal feed, and 3 per cent for biofuels (Steinfeld et al. 2012, Foley et al. 2011). The global research on livestock systems depicts great inefficiency in natural resource use in a wide range of livestock farming systems, a high geographic dispersion of extensive systems, and a geographic clustering of intensive systems. Livestock forms an important livelihood component for about one billion people, but only accounts for 1.5 per cent of the world's gross domestic product, 13 per cent of all dietary energy, and 25 per cent of all dietary protein. The production of animal protein is by far less efficient than the production of plant protein. Table 3 shows the distribution of the livestock populations and their productivity in relation to the production systems.

The importance of livestock in arid and semi-arid zones with fewer land use options is high in terms of animal heads, but their productivity is by far less than in temperate zones and highlands. Animals in the arid and semi-arid zones therefore show a high lifecycle/product GHG emission ratio.

Although the demand for livestock products in developed countries is stagnant, growing demands in developing countries over the past 30 years result in global annual growth rates of 6.6 per cent for poultry, 4.4 per cent for pork, and 3.2 per cent for mutton (Steinfeld 2012). They reflect a close relationship between meat consumption and per capita income (see figure 14, chapter 2.6.2). Consequently, such increased demands result in a higher needs for rangelands and fodder crops. Prices for fodder maize and soybean for example have increased since 2007.

Table 3 Livestock population and production in different production systems

Livestock type	Livestock production system								Agro-ecological zone		
	Grazing		Rainfed mixed		Irrigated mixed		Landless/ industrial		Arid & semi-arid	Humid	Temperate & highlands
	Global	Dev. countries	Global	Dev. countries	Global	Dev. countries	Global	Dev. countries			
Population (million head)											
Cattle & buffaloes	406	342	641	444	450	416	29	1	515	603	381
Sheep and goat	590	405	632	500	546	474	9	9	810	405	552
Production (million tons)											
Beef	14.6	9.8	29.3	11.5	12.9	9.4	3.9	0.2	11.7	18.1	27.1
Mutton	3.8	2.3	4.0	2.7	4.0	3.4	0.1	0.1	4.5	2.3	5.1
Pork	0.8	0.6	12.5	3.2	29.1	26.6	52.8	26.6	4.7	19.4	18.4
Poultry meat	1.2	0.8	8.0	3.6	11.7	9.7	52.8	25.2	4.2	8.1	8.6
Milk	71.5	43.8	319.2	69.2	203.7	130.8	0	0	177.2	73.6	343.5
Eggs	0.5	0.4	5.6	2.4	17.1	15.6	35.7	21.6	4.7	10.2	8.3

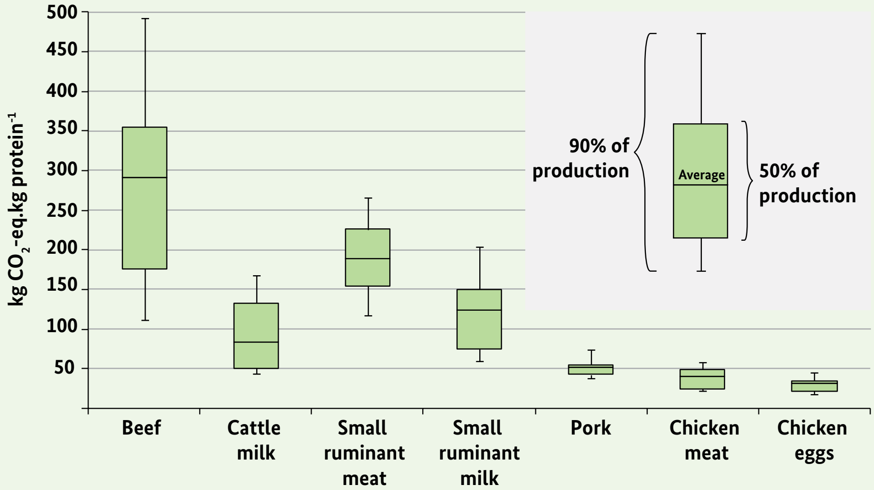
Source: Steinfeld et al. 2006, global averages 2001 – 2003

Total methane emissions from enteric fermentation by cattle (incl. buffaloes) amounted to 75.1 mt CH_4 in addition to 9.4 mt CH_4 by small ruminants in 2004 (Steinfeld et al. 2006). Livestock husbandry is a dominant activity in Latin America, Eastern Europe, Central Asia, semi-arid areas of Africa and Oceania. In these regions, methane from enteric fermentation is the most important source of GHG originating from agriculture. Projected increases of methane range between 35 and 60 per cent (2003 to 2030), depending on the livestock increase rates as well as on the degree to which mitigation techniques in feeding practices and manure management (see chapter 2.2.2) will be applied (FAO 2003, Smith et al. 2007).

A comparison of emissions from different animal types in relation to the produced proteins provides indications for potential mitigation measures through management (see figure 8). The evaluation reveals that beef production has by far the highest GHG emission rates.

GHG emissions in milk production depend on the productivity of cows. The relationship between milk output and GHG release reveals the inefficiency of livestock production in marginal production areas and extensive systems with low productivity (see figure 9). However, it must be noted that no other meaningful livelihood and income options may be available in such marginal areas.

Figure 8 Global emission intensities from different animal types and commodities



Source: adapted from FAO 2013c

Extensive grazing systems occupy vast areas of land despite an overall trend towards intensification. They are the only way to use the vast arid to semi-arid areas like in Central Asia, Latin America or the Sahel. Livestock production less dependent on grazing (esp. for poultry and pigs), tends to shift geographically from rural to urban and peri-urban areas to get closer to consumers facilitating more animal-friendly transport at limited costs. Transport costs for imported feedstuffs decrease as well, while manure may accumulate in industrial livestock systems and constitute a source of GHG if not properly managed (see chapter 2.2.2).

Increasing livestock numbers and livestock concentration push the livestock sector more and more into direct competition for scarce land and water. The expansion of livestock production is a key factor for deforestation in South America, where pastures occupy 70 per cent of previously forested land in the Amazon, and where feed crops cover a large part of the remaining areas of this land (see chapter 2.5).

It is worthwhile to mention that 20 per cent of the world's pastures and rangelands in total, but 73 per cent of rangelands in dry areas – where livelihoods depend heavily on them – are degraded to some extent, often through overgrazing, compaction and erosion created by livestock and deforestation. The degradation of these grasslands also disables their former function as carbon sinks (see chapter 2.5) and threatens livelihoods.

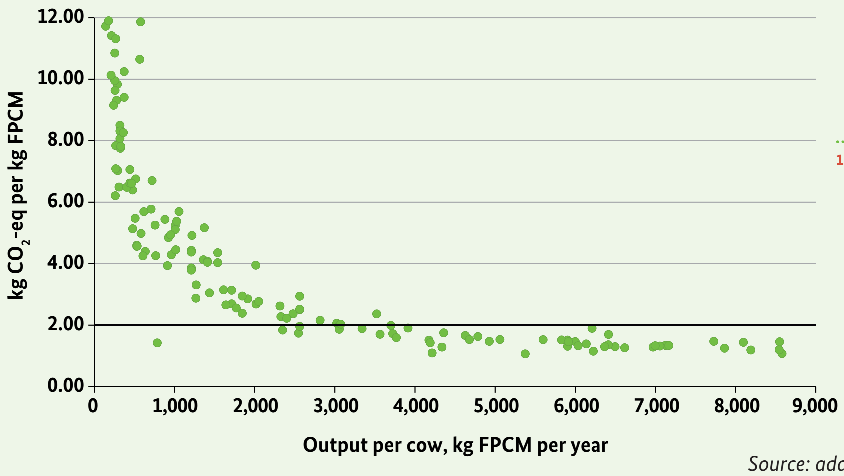
Grazing fees and the removal of obstacles to mobility on common lands can reduce overgrazing. In addition, appropriate grassland management (e.g. soil conservation, grazing bans, silvopastoralism, fire breaks and controlled burning, and exclusion of livestock from sensitive areas) reduces degradation.

2.5 Land use, land use change & forestry

Soil and biomass form huge carbon stores. Their storage capacity highly depends on the ecosystem and land use. It is generally high in wetlands, grasslands and forests. Croplands show the lowest carbon concentration (except deserts and semi-deserts), especially if the produced biomass is removed. Land cover, forests and undisturbed wetlands with high carbon storing capacity have dramatically reduced and are further reduced through human land use change and climate change (boreal forests). The converted land often does not serve any more as powerful carbon store.

The internationally agreed-upon classification system of GHG deems agriculture as one sector and 'Land Use, Land Use Change, and Forestry' (LULUCF), often only mentioned as 'land use change & forestry' or as 'forestry', as another sector. In practice, both sectors show intensive inter-linkages. The following analysis focuses on land use change caused by agriculture and on carbon pools and their potential for carbon sequestration in the carbon cycle (see also figure 1). The carbon stocks of terrestrial systems consist of the underground carbon stored

Figure 9 Relationship between total GHG and milk output/cow[13]



Source: adapted from FAO 2013c based on Gerber et al 2011

[13] Fat and Protein Corrected Milk (FPCM) output

mainly as soil organic matter or organic debris and the carbon stored above and underground by the vegetation. Table 4 shows the amount of carbon stored in the biosphere, as well as in the atmosphere.

Table 4 Selected global carbon stores

	Carbon stores (gt CO_2-eq)	%
1. Soil carbon	9,200	65.7
- Organic soil carbon	5,700	40.7
- Inorganic soil carbon	3,500	25.0
2. Biotic carbon	2,000	14.3
3. Atmospheric carbon	2,800	20.0
Total	**14,000**	**100**

Source: adapted according to Gattinger et al. 2011

The global soil carbon store of about 9,200 gt CO_2-eq is by far the largest carbon pool of the biosphere store. It is 3.3 times larger than the atmospheric store and 4.5 times bigger than the biotic pool (2,000 gt CO_2-eq) (Lal 2004, Gattinger 2011).

Carbon pools are generally saturated and well stored in undisturbed permanent systems such as oceans, forests, grasslands, wetlands, peatland and to a lesser extent agricultural land (see table 5). Important carbon pools are for example found in wetlands with anaerobic conditions where degradation of organic matter is prevented. When wetlands or peatlands are drained, much of their carbon stock is transformed into CO_2 and emitted to the atmosphere.

Table 5 Global carbon stocks in vegetation and top one meter of soils

Biome	Area	Carbon Stocks (Pg CO_2-eq)			Carbon stock concentration (Pg CO_2-eq M km^{-2})
	M km^2	Vegetation	Soils	Total	
Tropical forests	17.60	776	791	1566	89
Temperate forests	10.40	216	366	582	56
Boreal forests	13.70	322	1724	2046	149
Tropical savannas	22.50	242	966	1208	54
Temperate grasslands	12.50	33	1080	1113	89
Deserts and semideserts	45.50	29	699	728	16
Tundra	9.50	22	443	465	49
Wetlands	3.50	55	824	878	251
Croplands	16.00	11	468	479	30
Total	**151.20**	**1706**	**7360**	**9066**	**60**

Source: Bellarby et al. 2008/IPCC 2001

Intensively managed land has lower carbon stocks than natural vegetation. Wetlands have the highest carbon stock per square kilometre (8.4 x higher than cropland), followed by boreal forests (5 x higher than cropland). Tropical forests and temperate grasslands have similar carbon stocks that are only three times higher than those of cropland (see table 5). Total carbon stocks are highest in boreal forests due to their geographic expansion compared to other lands, followed by tropical forests, tropical savannahs, and temperate grasslands. Tropical, temperate, and boreal forests cover 27.6 per cent of the land surface, but hold 46.3 per cent of the carbon stocks, whereas croplands cover 10.6 per cent of the land surface, but contain only 5.3 per cent of the carbon stocks. The enduring expansion of croplands and grazing areas continues to reduce previous carbon stocks under forests. Previous carbon sinks continue to be converted into carbon sources. Boreal forests continue to be destroyed through temperature increase (global warming).

In the soil of croplands, organic carbon stocks differ considerably according to soil types and crops grown on the land. High soil carbon levels have beneficial effects, as they improve soil structure and fertility. Apart from the soil type, high soil carbon levels depend on high organic matter inputs (Gattinger et al.

2011). Restoring the soil biosphere's carbon pool provides a unique opportunity for the agricultural and LULUCF sector to mitigate climate change. In agriculture for example, integrating of humus-enriching crops in rotations, minimizing soil tillage, maintaining straw in the fields, and enriching fields with manure, compost and mulch, and integrating trees into the fields also enrich soil and biotic carbon. Soil carbon losses result from the cultivation of crops with few organic residues and limited soil coverage (e.g. sugar beet, potatoes, maize). Fodder or mixed crops (e.g. clover, grass, grain legumes, or inter-row crops) with intense rooting systems secure carbon gains (Gattinger et al. 2011).

The rate of land cover change increased sharply after 1945 (Bellarby et al. 2008). Since then most of the additional crop- and rangeland has been converted from tropical forests. Driving factors were increasing population in the past decades and today, and with the increase of global trade, the rising demand of animal feed like maize or soya for livestock production in high and middle income countries. However, the period of major expansion of agricultural activities into uncultivated lands may be over because suitable areas diminish with some exceptions in humid tropical regions (Desjardins et al. 2007 in Bellarby et al. 2008). In addition, reconversion of less productive croplands into forests is occurring simultaneously in temperate areas in Europe, North America, China, Japan, and South Korea. Despite an overall positive net balance of forest plantation areas (FAO 2006b), some tropical countries show continuing tremendous losses of tropical forest in favour of agricultural production (Foley et al. 2011). Overall, the forest carbon balance remains negative: gross deforestation continued at a rate of 12.9 million ha/year between 2000 and 2005, and the net loss of forest is currently estimated at 7.3 million ha/year (Nabuurs et al. 2007) with a decreasing trend (see table 6). Losses mostly occur in tropical forests, which have higher carbon concentrations and therefore emit more CO_2 into the atmosphere from each converted hectare.

Global trends of forest areas and changes reveal that after 2000 only in South America deforestation rates still increased (see table 6). In Brazil, carbon dioxide release from deforestation accounts for about 60 per cent of the total national emissions (Gattinger et al. 2011).

Table 6 Estimation of forest area and changes

Region	Forest area, (mill. ha)	Annual change (mill. ha/yr)		Carbon stock in living biomass ($MtCO_2$)			Growing stock in 2005
	2005	1990 – 2000	2000 – 2005	1990	2000	2005	million m³
Africa	63,5412	-4.4	-4.0	241,267	228,067	222,933	64,957
Asia	571,577	-0.8	1.0	150,700	130,533	119,533	47,111
Europe	1001,394	0.9	0.7	154,000	158,033	160,967	107,264
North and Central America	705,849	-0.3	-0.3	150,333	153,633	155,467	78,582
Oceania	206,254	-0.4	-0.4	42,533	41,800	41,800	7,361
South America	831,540	-3.8	-4.3	358,233	345,400	335,500	128,944
World	**3,952,026**	**-8.9**	**-7.3**	**1,097,067**	**1,057,467**	**1,036,200**	**434,219**

Source: adapted from Nabuurs 2007 /FAO 2006b

Conversion levels of different ecosystems into agricultural lands are projected to decrease by 2050. Most conversions are still expected from tropical and subtropical forests (coniferous and broadleaf forests, see figure 10).

Besides forests and grasslands, the conversion of natural wetlands into croplands also involves a loss of carbon stocks because of the decomposition of organic carbon. Additionally, conversion of wetlands causes other negative and irreversible effects on the environment. Many countries have therefore taken measures to protect remaining wetlands, e.g. through the Convention of Wetlands. The wetlands in South-East Asia for example, which hold immense fossil carbon stocks, are currently at risk of being drained and converted to cropland (Gattinger et al. 2011).

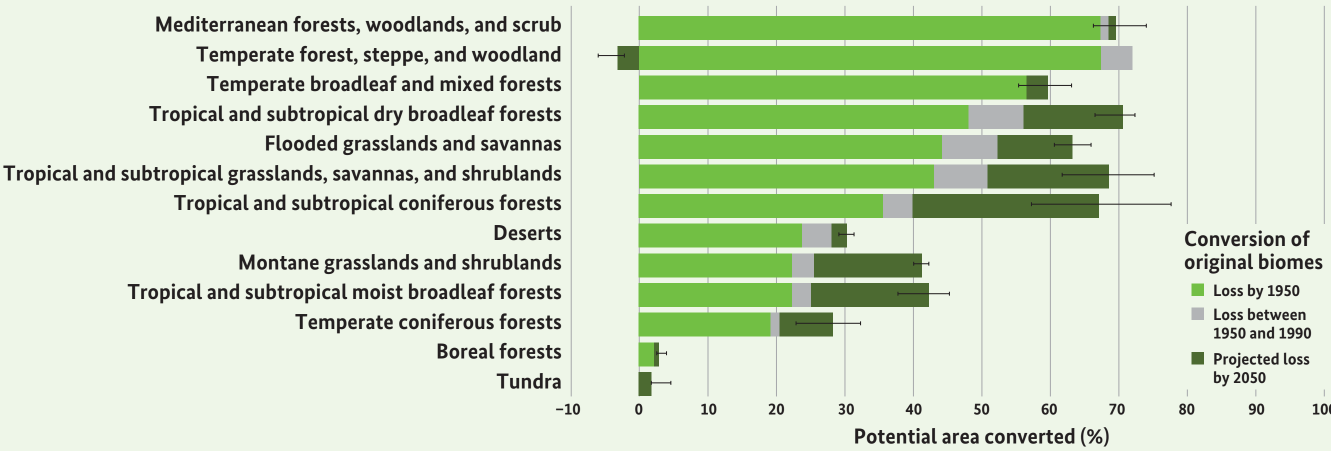
Livestock, as described in chapter 2.4, is among the biggest drivers of land use change. Increased livestock production has caused a shift from grazing to feed crop production and to concentrated supplementary feedstuffs such as cereals (Bellarby et al. 2008) in areas with intensive production. This conversion of grassland to cropland involves a loss of carbon. Intensive livestock operations are connected to a shift of production sites especially for pigs and poultry from rural areas closer to urban consumer areas. The separation of the sites for animal raising and production of animal feed involves high transport costs for animal feed and enhances competition for productive land between feed and food production. The extension of soybean production has negative impacts on the carbon balance of feed producing countries as it leads to deforestation and land conversion like in Brazil. At the same time, the carbon balance of livestock producing countries might improve, because land requirements for animal feed reduce here. The same inversion is encountered for biofuels, where biofuel using countries discharge their balance at the expense of biofuel producing countries (see chapter 2.5.3).

2.6 Other greenhouse gas emissions related to agriculture

The utilisation of fuel for pumped irrigation systems and agricultural machinery, as well as for the production of agrochemicals also has to be taken into account in the overall agricultural GHG balance. Processing, cooling and storage, transporting and cooking of agricultural produce also consume energy. Considerable amounts of foodstuffs are wasted during this chain between farmers and consumers. They increase the lifecycle emissions and carbon footprint of the produces, as well as the volume of required food to be produced to ensure overall food security. Biofuels increase the GHG release from agriculture, while they decrease the GHG balance in other sectors where they are used to replace fossil fuels (transport and energy).

There is considerable inter-linkage between different GHG-producing sectors as shown on page 6. On the upstream side, the use of fuel for agricultural machinery, cooling and heating of buildings as well as the production and transport of agrochemicals are the most important sources. On the downstream side, the energy used for the transport of produce, as well as for the processing and refrigerating of food, have to be considered. In addition, there are a number of non-valorised by-products, unused products, and waste, which produce GHG during their decomposition or removal.

Figure 10 Status of conversion of ecosystems into agricultural lands



Source: adapted from World Bank 2010

2.6.1 Upstream GHG emissions

'Indirect' GHG emissions in the agricultural sector correspond to 16 per cent of the agricultural sector's GHGs including fuel for agricultural machinery (3 per cent), irrigation and buildings (6 per cent) as well as the production of agrochemicals (7 per cent) (Bellarby et al. 2008), as shown in table 2 (see chapter 2.1) and on page 6. Transport of inputs to the farms also requires attention, e.g. animal feed from abroad.

Irrigation occupies the largest share of fuel consumption for water pumping (elevation). However, modern tillage and combine harvesting machineries in developed countries, as well as the application of agrochemicals, show a wide range of high-end values for fuel consumption (see table 7).

Table 7 GHG emissions from fossil fuel and energy use in farm operations and production of chemicals for agriculture

	kg CO_2-eq km^{-2}	Pg CO_2-eq
Tillage	440 – 7,360	0.007 – 0.113
Application of agrochemicals	180 – 3,700	0.003 – 0.057
Drilling or seeding	810 – 1,430	0.015 – 0.022
Combine harvesting	2,210 – 4,210	0.034 – 0.065
Use of farm machinery	**Subtotal**	**0.059 – 0.257**
Pesticides (production)	220 – 9,220	0.003 – 0.14
Irrigation	3,440 – 44,400	0.053 – 0.684
Fertiliser (production)	–	0.284 – 0.575
Total		**0.399 – 1.656**

Source: adapted from Bellarby et al. 2008

According to the Millennium Ecosystem Assessment (2005), 18 per cent of the world's croplands receive supplementary water through irrigation. The carbon release through energy consumption of irrigation is slightly lower than the productivity increase achieved with reduced GHG/unit. Therefore powered irrigation systems cannot be entirely positioned on the negative side of the carbon balance. However, the effect of GHG from higher nitrogen utilization in the usually more intensive irrigated production will also have to be taken into account.

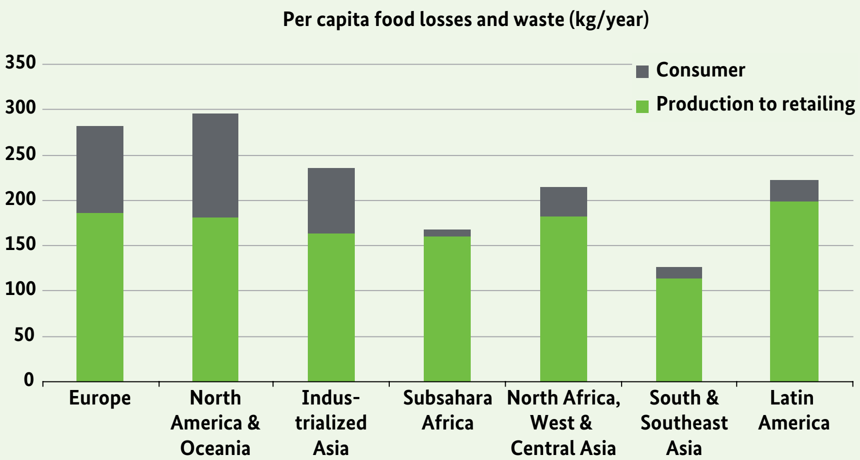
The production of nitrogen fertilizer is extremely fuel-intensive and accounts for considerable GHG emissions in China, North America, and Europe. Nitrogen fertilizer production alone accounts for 1.4 per cent of the total global GHG release (recorded in the industrial sector).

2.6.2 Downstream GHG emissions

Considerable amounts of fuel are used for the transport and processing of agricultural produce and the refrigerating of perishable foodstuffs. The transport of food is fully accounted in the transport sector. However, from a GHG point of view, the long shipping of bulk feed to livestock farms before its conversion into higher value meat is always less efficient in comparison to the transport of the less voluminous and already converted high value product.

The processing of food is particularly energy-intensive in the dairy sector, which requires considerable energy for refrigeration. Transport of meat products generally cover long distances and require refrigeration (FAO 2009a).

Figure 11 Per capita food losses and waste in different regions (at consumption and pre-consumption states)



Source: adapted from Gustavsson et al 2011

At the consumer's side, the cooking time of foodstuffs also needs to be considered for the full GHG balance. The cooking time of different varieties of rice, beans and other foodstuffs greatly differs and the energy efficiency of cooking systems as well.

Numerous other energy and carbon losses are encountered because of losses and wasting i.e.:
- post-harvest losses due to pests and diseases, losses during harvest, transport and storage,
- wastage of by-products such as straw, molasses, high protein residues of oil extracts, inefficient use of manure, that are not always used or appropriately recycled especially if transport is considered,
- products not conforming to commercial standards, e.g. products not conforming with trade classifications due to differing sizes and weight, and
- wasted agricultural produce, especially easily perishable foodstuffs not sold in time or not consumed in time and thrown away by consumers. They may also produce additional GHG during decomposition.

The total food waste amounts to 1.3 billion tons/year and was estimated at 95 to 115 kg/year/consumer in Europe and North America, but only at 6 to 11 kg/consumer/year in Sub-Saharan Africa and South-East Asia (see figure 11). In total, the food waste is estimated at one third of the production (Gustavsson et al. 2011). The influence of food losses on the ecological footprint of different crops can be assessed through life cycle assessments following the principles shown in figure 12.

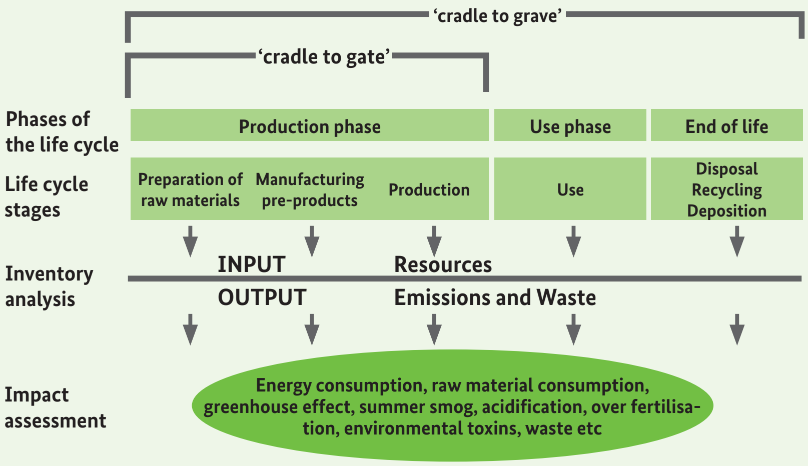
Although the present review cannot consider these aspects in depth, some linkages between food losses and mitigation potentials should be taken into account in regard to breeding objectives (e.g. perishability and resistance to pests and diseases), farm organization (efficiency of the carbon cycle and recycling), and general appreciation of food and nutrition and sensitization for more climate-friendly consumption.

2.6.3 Production and utilization of biofuels

Biofuels have the potential to substitute fossil fuels that experience continued price increases and growing future shortages. Thus, biofuels as renewable energy source have not only attracted great interest as an overall mitigation strategy, but have also stimulated controversial debate. The reduction of GHG emissions in the transport sector will be countered by an increase of GHG in the agricultural sector due to energy requirements for the production of biofuel crops and the increased competition for productive agricultural lands for food production. Since productive areas are already rare, additional land demands also impose further pressure on marginal land and forested land. Production of biofuels is therefore likely to contribute to increases in food prices. It thereby challenges the global efforts to improve food security and reduce poverty, and constitutes a source of conflict.

Challenges of foreign direct investment in land ('land grabbing') for bioenergy production and of land ownership pose additional complications. In contrast to the explicit production of bioenergy crops, the recycling of farm residues (e.g. straw, manure, or food processing residues) is considered as an option for energy cycle management and efficiency.

Figure 12 Principles of the life cycle assessment scheme



Source: adapted from GIZ 2013

Table 8 Main emission scenarios for the period 1999 to 2099 – SRES storylines

A1: strong and rapid economic growth, peaking population about 2050 and technological efficiency progress: ▸ subgroups with different energy resources (fossil – non-fossil – mixed) ▸ rather flat emissions Estimates: temperature increase + 2.4 – 4°C	B1: convergent world with peaking population growth, strong and rapid economic growth towards services and information economy and stronger emphasis on environmental concerns: ▸ tendency for reduced emissions Estimates: temperature increase + 1.8 °C
A2: ongoing population growth, slow economic growth and development but little technological progress in developing regions (less globalization): ▸ highest emissions Estimates: temperature increase + 3.4°C	B2: intermediate population and economic growth with less globalization (local solutions) but some emphasis on environmental concerns: ▸ less high increase in emissions Estimates: temperature increase + 2.4°C

Source: IPCC 2000/IPCC 2007

2.7 Future scenarios, trends, driving factors and boundaries

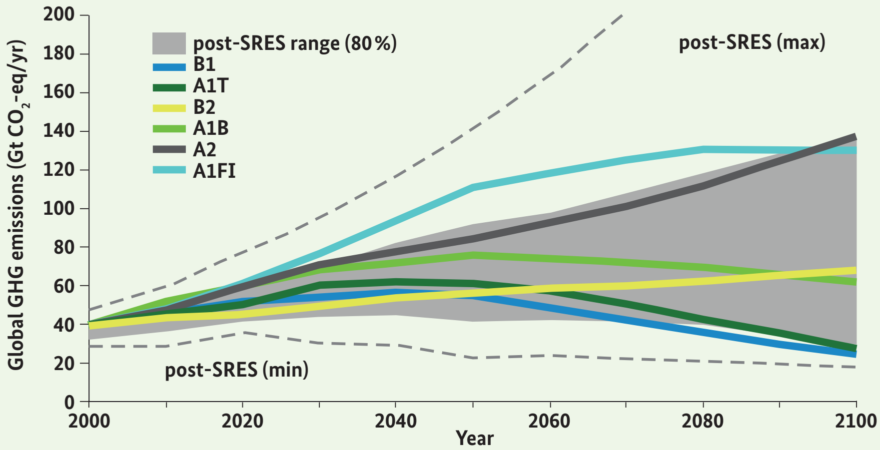
The projected scenarios on global warming expect a temperature increase between 1.8 and 4° for the present century, depending on the assumed population growth rate, economic growth, technological progress and the extent to which environmental concerns will be taken into account. The growing world population with changing diets (increased meat consumption) has unfavourable GHG effects, while technological progress leads to increased agricultural productivity and partly alleviates the GHG balance.

2.7.1 Future scenarios and trends

IPCC developed emission scenarios in 2000 in its 'Special Report on Emission Scenarios' (SRES), which has been updated in 2007. In 2003, the FAO elaborated projections on 'World Agriculture: Towards 2015/2030'. In 2006, the United States Environmental Protection Agency (US-EPA) also developed its projections. The methodologies, the observed timelines, as well as the strengths and weaknesses of the projections differ. The SRES for example is organized according to four 'storylines' shown in table 8 [14].

[14] Currently, IPCC is developing new scenarios. The available data on climate change projections (IPCC working group I) consider six representative concentration pathways (RCP), which are based on four new scenarios identified by their approximate total radiative forcing in year 2100 relative to 1750 (IPCC 2013). Other elements of the future scenarios such as economic development, population and environmental behaviour make part of the upcoming reports of working group II and III in 2014.

Figure 13 SRES Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies



Source: adapted from IPCC 2007, Synthesis report

Although this analysis does not well integrate land use changes, it takes mitigation efforts into account. The FAO forecast shows largely similar trends, while the US-EPA differs in some aspects. Despite some differences in projected population growth dynamics and economic growth, the overall emission rate scenarios do not differ significantly from the projections made in 2000. Nonetheless, some assumptions still remain vague, e.g. the technological progress and change through the adoption of new techniques. All SRES scenarios refer to the current climate policies without assuming additional policies and regulations. A detailed description of these scenarios is included in annex 3.3. The corresponding emissions are shown in the following graphs (see figure 13).

The other projections only consider the period until 2020 (US-EPA) or 2030 (FAO). For these periods, all projections take increased GHGs for agriculture into account (10 to 15 per cent per decade). The most important increases are assumed for the livestock sector (methane) because of increased animal numbers (up to 60 per cent increase until 2030, FAO 2003). At this time (2030), agriculture will produce 8.3 gt CO_2-eq/year, which constitutes an unchanged or even slightly increased share of 15 per cent of total GHG (Gattinger et al. 2011, Baumert et al. 2005).

The consequences of climate change in turn amplify the emission of GHG:

- productivity decreases as a result of high temperatures, irregularities and climate stress, combined with harvest losses and reduced carbon stocking capacity;
- efficiency of energy use in agricultural production reduces because of similar energy inputs, but decreasing yields;
- forests become more vulnerable to pests, drought and therefore less productive in terms of carbon stocking capacity;
- practices unadapted to climate change result in land degradation and reduce the potential to restore carbon in the future or increase the costs to do so.

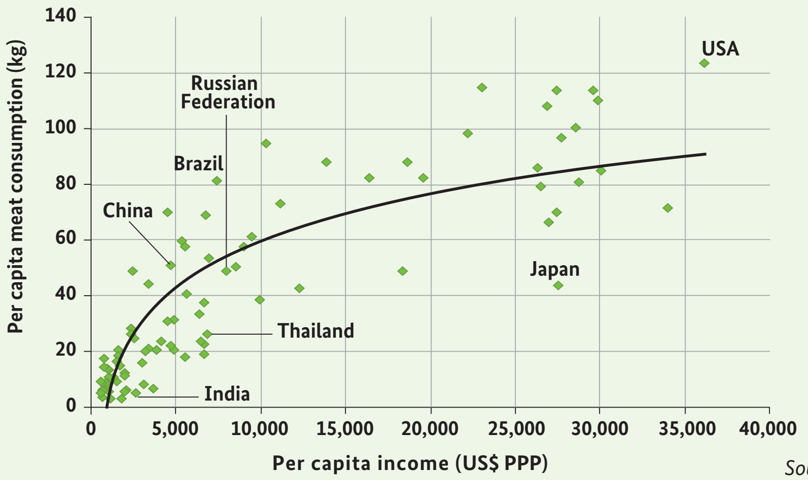
2.7.2 Key drivers and boundary conditions for greenhouse gas emissions

The world population with currently 7,058 billion (2012) is expected to increase to 9,624 billion in 2050. At the same time, the share of people in least developed countries will rise from 12 per cent to 20 per cent (PRB 2012) with high growth rates in Africa and medium growth rates in Asia. Beyond 2050, the projections differ significantly (UN 2011a, UN2011b, PRB 2012). It is undisputed that life expectancy will increase, especially in less and least developed regions, and that the urbanization trend will continue, especially in less developed regions.

These population trends imply an increasing demand for energy and food. Since there is only a limited potential for cropland expansion, an increase in agricultural productivity is inevitable. The assessment of agricultural productivity between 1985 and 2005 is controversial and was downsized from 47 per cent (FAOSTAT 2011) to a net increase of about 20 per cent (Foley 2011).[15] The future productivity

[15] The analysis is based on all crops and on the harvested area (consideration of cropping intensity) and increased cropping area.

Figure 14 Relationship between meat consumption and per capita income in 2002



Note: National per capita based on purchasing power parity (PPP)
Source: adapted from World Bank 2006 and FAO 2006a

increases will require additional technological progress and access to these technologies as well as access to agricultural inputs in developing countries. Among these inputs, especially nitrogen fertilizer will strain the carbon balance. Furthermore, the continued urbanization trend in developing regions will probably require substituting human labor in rural areas by machinery and its respective energy use.

Increased incomes in Asia and continued industrialization and urbanization stimulate changing nutritional diets in urban areas: diets will include more meat, as shown in figure 14 for the past. Changes in staple foods, also in least developed countries, will have to be considered. The transport of food to more people in urban areas, but also from productive temperate to increasingly less productive tropical areas (see figure 7 and annex 3.3) will require surplus fuel.

Increasing demands for food and meat will challenge overall food security because of limited land resources and boundaries to productivity increase. At present, 75 per cent of agricultural lands are devoted to the raising of animals (Foley et al. 2011). Furthermore, the competition for land resulting from biofuels adds to these constraints. Negative consequences on food prices are already observed and food prices are expected to increase in the future. The group of food insecure people will increase with these price developments. The inability to assess sufficient food will imply other constraints such as favouring unsustainable land use practices and land degradation (Beddington et al. 2011) and thus impede capacities to increase carbon stocks. The UNCCD estimates that 12 million hectares of land are lost per year because of land degradation, which could potentially produce 20 million tons of grain (Beddington et al. 2011). The higher meat demand will increase emissions and challenge global food security (see figure 15).

Although unreasonable in terms of carbon balance and food production, economic drivers encourage deforestation in tropical areas in favour of palm oil, soybeans and energy crops (Foley 2011, Solymosi et al. 2013). The least expensive way to combat climate change in agriculture is to preserve those forest areas. Restoring the carbon sinks of degraded land in tropical forest and dry areas is considerably more expensive (see chapter 2.5).

The consequences of growing food insecurity through the described circle need to be managed by the international community to avoid a vicious circle of poverty, land degradation and, in consequence, political turmoil and violent crises.

Figure 15 Comparative GHG emissions from different food products

Food item (1 kg)	Emissions (kg CO_2e)	Driving distance equivalent (km)
Potato	0.24	1.2
Wheat	0.80	4.0
Chicken	4.60	22.7
Pork	6.40	31.6
Beef	16.00	79.1

Source: adapted from World Bank 2010

3

Mitigation of greenhouse gas emissions in agriculture and land use change

3.1 General considerations on the potentials for GHG mitigation

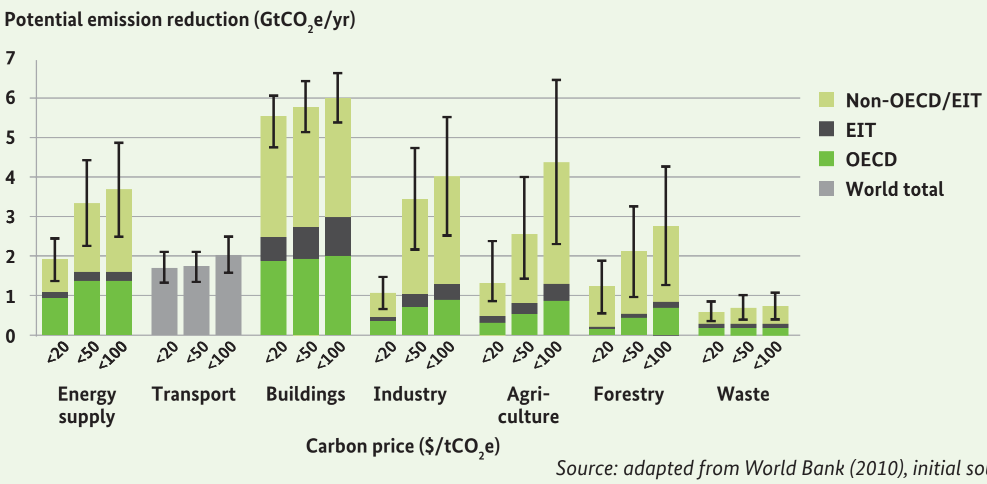
There are three GHG mitigation options in agriculture and land-use change & forestry: (i) increasing carbon dioxide storage in soils and biomass, (ii) reducing emissions during agricultural production, and (iii) indirectly, reducing the required volume of agricultural production. Many low-income countries theoretically have a positive GHG balance, since their technical potential for carbon sequestration exceeds the volume of their GHG releases. The challenge of feeding the global population and reducing agricultural GHG emissions requires the successful transfer of climate-friendly agricultural and land use practices to farmers that are useful for adaptation and mitigation. It requires an increase of agricultural productivity with a minimum GHG release per product. The reduction of food wastage and the adaptation of more climate-friendly diets can reduce pressure from food production on limited land. Improved family planning to reduce population growth is another important area of action.

Both sectors, agriculture and land use change & forestry, provide a wide scope for mitigating GHGs. They are sources of GHG emissions and carbon sinks at the same time since they involve the unique possibility of removing considerable quantities of carbon dioxide through carbon sequestration. This offers two direct and one indirect mitigation option:

1. Enhancing the removal of GHG from the atmosphere by enlarging carbon sinks through increased soil organic matter and biomass;
2. Reducing direct and indirect GHG emissions from agricultural production and land use change through improved management practices, e.g. decreasing the release of nitrous oxide, methane and CO_2;
3. and indirectly, reducing the required volume of agricultural production by more climate-friendly diets (i.e. less livestock feed and meat), reduced food losses and waste and improved energy cycle management, but with less biofuel crops, which add conversely on the volume of agricultural production.

The total carbon sequestration potential in agriculture and land use (option 1) is 6 gt CO_2-eq/year, which corresponds roughly to the emissions from each of the two sectors (see also chapter 3.1). The sequestration potential corresponds to the carbon stocks in different types of vegetation as shown in table 5 (see chapter 2.5), but also depends on cropping intensity and residue management.

Figure 16 Potential emission reductions at different carbon prices (USD)



Source: adapted from World Bank (2010), initial source: Barker and others (2007b)

Figure 16 shows the emission reduction potential of option 2 across all emission sectors in the different categories of countries at different carbon prices. Compared to other emission sectors, there is an important reduction potential in the agriculture and in the land use & forestry sector in developing regions (non-OECD/EIT[16] countries), which could be achieved at reasonable costs of less than 20 USD/t CO_2-eq. Only the building sector offers higher saving potentials at this price. However, current carbon prices of about 10 USD/t CO_2-eq do not work in favour of such reductions.

The following map shows the regional GHG mitigation potential in agriculture based on SRES scenario B2. It differs largely between the regions. This technical mitigation potential is comprised of 89 per cent from soil carbon sequestration, 9 per cent from methane emission reduction and 2 per cent from nitrous gas emissions reduction. Accordingly, those areas with a high potential for sequestration show relatively higher values. Low income regions, which have fewer GHG emissions (see figure 3) offer a high potential for mitigation in terms of carbon sequestration, which may become an interesting income source if considered by carbon financing mechanisms.

Option 3 (climate friendly diet and waste reduction) is mainly based on reduced land requirements for livestock and feed production and so engenders reduced GHG emissions in both sectors, agriculture and land use change. Figures 17 and 18 give some ideas on the global GHG reduction potential in this regard.

[16] Organization for Economic Cooperation and Development / Economies In Transition

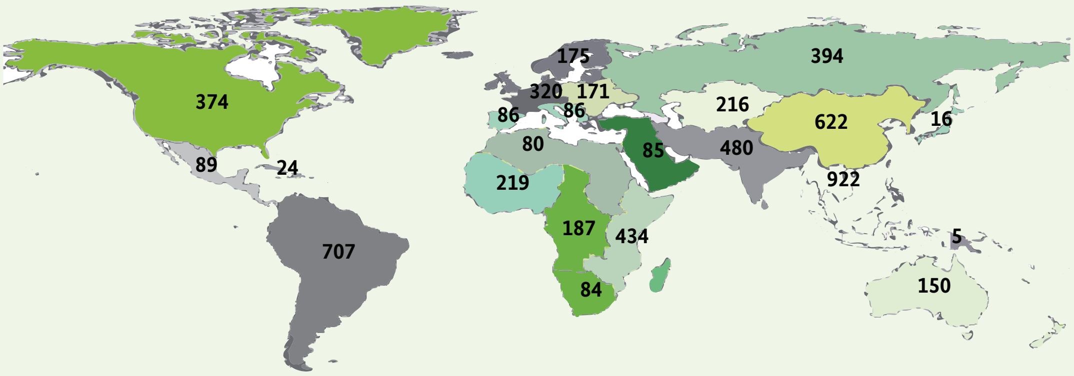
The share of food crops in agricultural production is particularly high in Africa and parts of South-Eastern Asia, but South America and many industrialized regions have a high share of feed crops and other non-food products. Mitigation policies will have to take this global scenario into account and concentrate on the latter countries to have effective outcomes.

Mitigating agricultural GHG emissions faces the challenge of increasing food requirements in developing regions (see chapter 2.6). To meet the increasing food demand (see figure 19), IFPRI has developed a 'safe operating space', which connects food and climate systems. The green safe operating space is enclosed with three limits, which will have to be enlarged as much as possible:

A. the maximum quantity of food that can be produced, which is, however, limited by on-going effects of land degradation due to inappropriate land management practices and climate change,
B. the nutritional needs of the increasing global population that can be satisfied to the extent that diets can be adapted, and food is used efficiently without wastage,
C. and the mitigation of climate change, which can be enhanced by climate friendly farming practices.

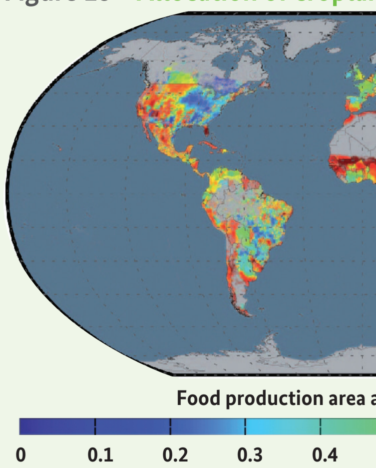
IFPRI states that current agricultural production does not fall within these 'safe space' limits. In 2050, it is still expected to remain outside these limits although the quantity of food produced will increase through technological progress, provided that the current scenarios realize. The challenge will be to transfer food production and utilization systems into the green safe space rapidly before large areas of operating space get lost by the effects of climate

Figure 17 Total technical mitigation potential in agriculture by 2030 (all practices, all GHGs, mt CO_2-eq/year)



Source: adapted from Smith et al. 2007

Figure 18 Allocation of croplar



Source: Foley et al. (2011) acc

change on agricultural productivity[17]. To enlarge the safe space on the one hand, and to move into the safe space on the other hand, Beddington et al. (2011[18]) suggest to work on these three limits via five areas of action:

- ensuring more equitable access to food,
- eliminating food waste in supply chains,
- moving towards more resource and climate efficient vegetable-rich diets,
- adapting food systems to climate change through agricultural innovation and existing best practices,
- mitigating (agricultural) GHG to keep the global climate within a tolerable range.

In addition to IFPRI's areas of action, reducing population growth by awareness creation, information and education offers another field of action.

The following chapter 3.2 will mainly explore the mitigation option in agriculture and land use change (option C)[19], but without compromising neither options A and B nor environmental concerns. It will be based on the technical mitigation potential while considering economic aspects and financial compensation mechanisms.

Not only the technological development to further increase productivity, but also the transfer of low emission practices to the farmers, constitute challenges. Access to improved practices will require a minimum level of understanding and a certain investment capacity of rather poor population groups. Investments or change of practices are likely to be accepted in case of quick win solutions that secure and increase production, food security and income. Saving emissions as such is not an attractive objective. In addition, governments will have to provide appropriate framework conditions and extension services capable to reach the farmers in the rural areas.

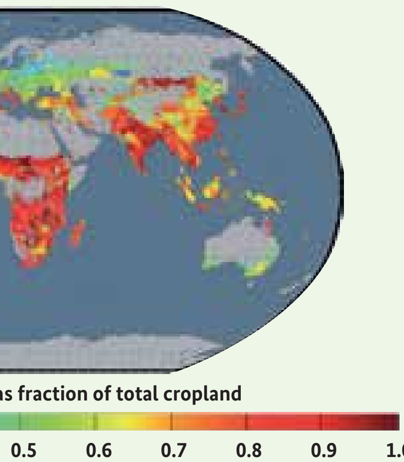
A climate-friendly, comprehensive system to exchange agricultural products between developing and developed countries is required to reduce emissions. It will have to be supported by adequate global trade policies. Such an exchange implies climate-friendly consumption patterns and sustainable management of available resources. This implies both, climate sensitive agriculture and consideration of other environmental concerns as outlined in the conventions on combating desertification, on protecting wetlands, on biodiversity and on the policies for appropriate management of water resources. Finally, the displacement of emissions between regions and sectors should be avoided unless it is justified by overall advantages and efficiency in global GHG mitigation, e.g. the replacement of fossil fuel through bioenergy or unnecessary land use change with carbon losses.

[17] Land degradation through inappropriate practices also contributes to the destruction of agricultural productivity (not analysed separately is this context).

[18] An animated version of this diagram can be accessed at http://bit.ly/SafeSpaceClimateFood.

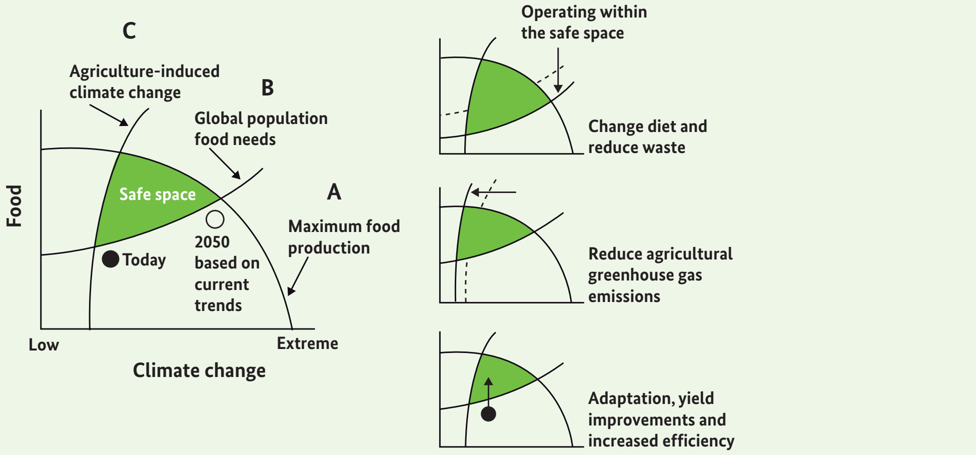
[19] Other options, which have the potential to increase the safe space, are also mentioned (A, option 1). The adaptation of agriculture to climatic change conditions (B), which could potentially bulge/buckle the maximum food production curb in favour of the safe space, is the subject of many other documents and is not taken into account here. Equitable access to food is also not explored in this document.

nd area to different uses in 2000



rding to data from FAOSTAT centred over 7 years

Figure 19 Safe operating space for interconnected food and climate systems



Source: adapted from Beddington et al. 2011

3.2 Technical measures to mitigate greenhouse gases

The technically feasible mitigation potential of agricultural management practices amounts to about 6 giga tons/year of carbon dioxide (equivalents) and could counterbalance the GHG released from either agriculture or from land use change. However, the economically feasible mitigation potential is less: at costs of 100 USD per ton of carbon dioxide (equivalents), 73 % of this technically feasible mitigation potential could be achieved. At a carbon price of 20 USD per ton, 28 % of this potential could be achieved. However, the current carbon price in emission trading schemes is less than 10 USD, which shows the limited mitigation potential that could be feasible through carbon funding. Since international funds for these public climate benefits are not sufficiently available, mitigation measures have to offer other incentives than payment to facilitate their adoption by farmers, such as increases in yield, food security or income. The most efficient mitigation potential is the renouncement to forest and wetland destruction, whereas the restoration of grasslands and degraded lands is considerably more expensive.

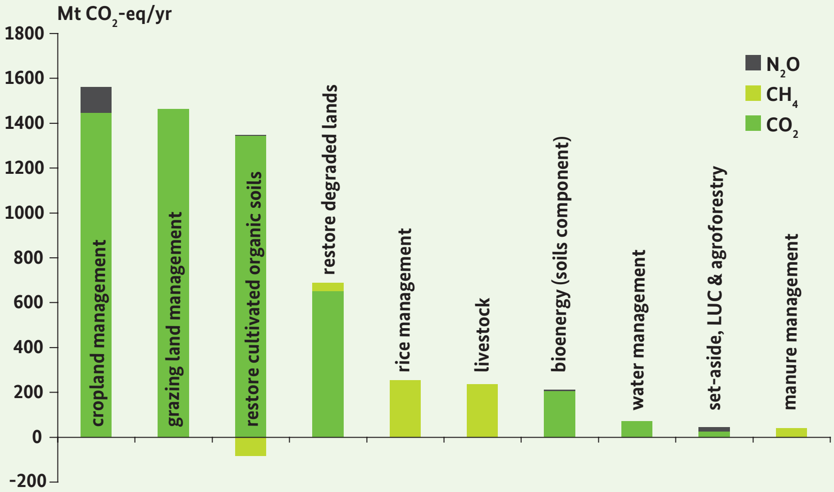
Figure 20 shows the global technical mitigation potential of different agricultural management practices by 2030. It illustrates their impacts on each GHG with a high share of carbon sequestration similar as shown in figures 17 and 18 [20].

The maximum global Technical Mitigation Potential (TMP) is 6 gt CO_2-eq/year, whereas the feasible Economic Mitigation Potential (EMP) is around 1.5 gt CO_2-eq/year at a carbon price of 30 USD per ton (Gattinger et al. 2011, table 9). The TMP is in the range of the total emissions from agriculture (estimated at 5.1 - 6.1 gt CO_2-eq/year) or from land use change & forestry (estimated at 5.9 gt CO_2-eq/year). According to different sources and sub-sectors, the TMP differs largely. Figure 21 shows that improved management of crop- and rangelands and the restoration of organic and degraded soils can realize the most important technical mitigation potential. However, targeted mitigation in rice cultivation and livestock management may offer opportunities in those countries with great importance of these sub-sectors (e.g. India for rice, Brazil for livestock).

The estimates of the global EMP at different costs in 2030 reported in Smith et al. 2007 are shown in table 9.

[20] This maximum technical mitigation level is composed of 89 per cent of carbon sequestration, of 9 per cent methane emission reductions, and of 2 per cent nitrous oxide emission reduction (according to Smith 2008 in Bellarby et al. 2008).

Figure 20 Global technical mitigation potential of agricultural management practices by 2030



Source: adapted from Smith et al. 2007

Table 9 Global technical mitigation potential of agricultural management practices by 2030

Carbon Price (USD/t CO_2-eq)	EMP (gt CO_2-eq/year)	EMP (% TMP)
20	1.5 – 1.6	28 %
50	2.5 – 2.7	45 %
100	4.0 – 4.3	73 %

Source: Smith et al. 2007

The mitigation costs for each measure (see figure 21) reveal that only a limited part of the technical mitigation potential can be achieved at low costs of up to 20 USD/tCO_2-eq, except for cropland management. Rice management shows a relatively better economic outlook since a substantial share of the technical potential can be achieved at limited costs. In contrast, the restoration of degraded lands (re-conversion of organic soils and restoration of degraded lands such as grasslands) are by far more expensive.

The high price of the land restoration indicates that prevention of the conversion or degradation of wetlands and other ecosystems with high storage capacity into cropland is far more practical than the restoration of these lands. The same holds true for forest destruction and reforestation (see table10). It is thus more pragmatic and cost-efficient to avoid land degradation through unsustainable agricultural practices.

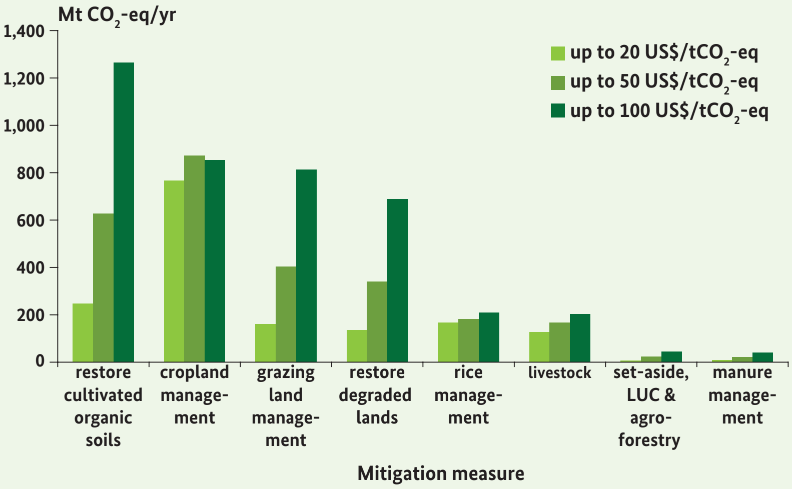
Comparing the overall economic mitigation at a price of 20 to 30 USD/CO_2-eq of around 1.5 gt CO_2-eq/year and the emissions of 5.1 to 6.1 gt CO_2-eq/year from agriculture and of 5.9 gt CO_2-eq/year from land use change shows that only insufficient mitigation is possible through carbon financing at low prices. Therefore more important incentives are required to achieve mitigation. Such incentives can only be derived from technologies that offer direct benefits in terms of increased yields, input savings or reduced losses.

According to the IPPC (Smith et al. 2007), soil carbon sequestration is the mechanism that holds the greatest technical mitigation potential within the agricultural sector with 0.4 to 1.2 gt CO_2/year corresponding to 5 to 15 per cent of global emissions. Improved grassland management and the restoration of degraded soils together have the potential to sequester about 2 gt CO_2/year by 2030. Grasslands store more carbon in soils than in the vegetation. Since grasslands occupy large areas, 36 per cent of total carbon storage is ensured in grasslands in dry areas. Therefore, improved rangeland management could sequester more carbon than any other practice (FAO 2009b).

Both, the absolute carbon sequestration potential and the length of carbon sequestration, have to be taken into account when looking at most feasible and efficient options. This sequestration length alters with the pace of decomposition of organic matter and is higher for wood than for easily decomposable organic matter. There are also interactions between different gases, with altering emission rates according to the management practices [21]. Further-

[21] Emission rates of the different gases can have multiple reduction effects (positive synergies enhancing GHG sequestration) or trade-offs between gases (counteracting effects) according to the nutritional state of soils and their management.

Figure 21 Economic potential for agricultural GHG mitigation by 2030 at a range of carbon prices



Source: adapted from Smith et al. 2007 more, the sequestration potential depends on local characteristics of agricultural environments like temperature and moisture. The annual mitigation potential for four climatic regions is demonstrated in annex 3.4. The extent to which the different measures contribute to mitigation still requires further investigation, since the results of numerous studies reveal significant differences.

Concerning forestry, the most economic mitigation options (see table 10) are reduced deforestation, whereas forest management requires higher costs.

Table 10 Technical forest mitigation potential

Activity	Potential at costs equal or less than 100 USD/t CO_2 (in Mt CO_2/year in 2030)			
	Total	Fraction < 20 USD/t CO_2	Fraction 20 – 50 USD/t CO_2	Fraction 50 – 100 USD/t CO_2
Afforestation	4,045	0.40	0.28	0.32
Reduced deforestation	3,950	0.54	0.28	0.18
Forest management	5,780	0.34	0.28	0.38
Total	**13,775**	**0.41**	**0.28**	**0.31**

Source: Nabuurs et al. 2007

More than 40 per cent of the forest mitigation potential can be obtained at costs less than 20 USD/t CO_2, and in Africa, about 70 per cent of the mitigation potential can be achieved at this price. A full economic scenario of the forestry mitigation potential according to regions is included in annex 3.5.

The assumptions about the mitigation potential at various carbon prices generally differ according to their approach: bottom-up studies show a more diverse cost potential and higher cost ranges compared to top-down studies as shown in annex 3.6 (Smith et al. 2007). The total mitigation potential in the land use change & forestry sector is estimated as much higher and less expensive than in top-down studies (Nabuurs et al. 2007).

In the following, the technical mitigation measures are analysed according to the most efficient mitigation practices. Many measures aim at increasing the carbon content in agricultural soils. The efficiency and longevity of this rather short-term and reversible carbon store compared to other natural stores (e.g. undisturbed forest soils or stones) depends on the carbon saturation of soils and on a number of agro-climatic factors like temperature, soil humidity, and crops.

3.2.1 Restoration of degraded land, land use and forestry

> Technical progress in agriculture will result in further productivity increases in the future. The rate of productivity increase is however not known. Agricultural productivity can particularly be increased in those mainly temperate areas in the northern hemisphere, where potential yields are expected to be higher than those currently achieved. The requirement of cropland for food production reduces accordingly. If these developments occur and opportunity costs for other cropping options are not encountered, restoring degraded lands and better managing crop- and grazing land allows considerably improved carbon sequestration.

Reducing the pressure on already degraded or non-agricultural land requires sustainable productivity increases on the current agricultural land for the expected 9 billion people in 2050. There is unanimity that the technological progress will continue and allow yield increases in the future. However, the magnitude of productivity increases in the past was assessed differently (see chapter 2.7.2). According to Foley (2011), deforested former tropical forest areas currently do not contribute much to food production, because many feed and biofuel crops are grown here. Based on results of different country studies, it is assumed, that on a global scale, cessation of deforestation would not have major impacts on palm oil and soybean prices and many agricultural activities could be shifted to other croplands without a significant fall in productivity (Stern Review 2007/2011). The respective losses of food production potential from converted but often degraded and rather unused former forest areas could be offset elsewhere in the food production system, e.g. by increasing productivity in other agricultural zones with important 'yield gaps' (see annex 3.7)[22]. Such efforts could contribute to reducing pressure from tropical forest areas.

These yield gaps offer important potentials to increase food production are found in Eastern Europe, Northern India and Northern China, parts of North America but also in Brazil, Argentina, Nigeria, and in areas of South-Eastern and West Africa. In case that the 16 most important food crops harvest 75 per cent of their potential yield, a 28 per cent increase of calorie production can be achieved. In case these 16 food crops are only used for human consumption (no animal feed or bioenergy), another 28 per cent more calories can be made available compared to the present situation. Additional increases are expected from genetic improvements with regard to increased yields and higher tolerance against pests and climatic irregularities (Foley 2011). Working on the yield potential for less common crops with fewer breeding efforts in the past (in addition to the 16 most used crops) could also enhance food production and crop diversity. However, these potential increases do not sufficiently account for the environmental degradation and increasing GHG through nitrogen fertilizer use, and the net benefit in terms of GHG is a bit less than projected. The costs of environmental degradation are estimated in a wide range (UNCCD 2012). The restoration of degraded rangeland along with sustainable livestock management systems is expected to show considerable co-benefits on GHG mitigation (Unique 2012).

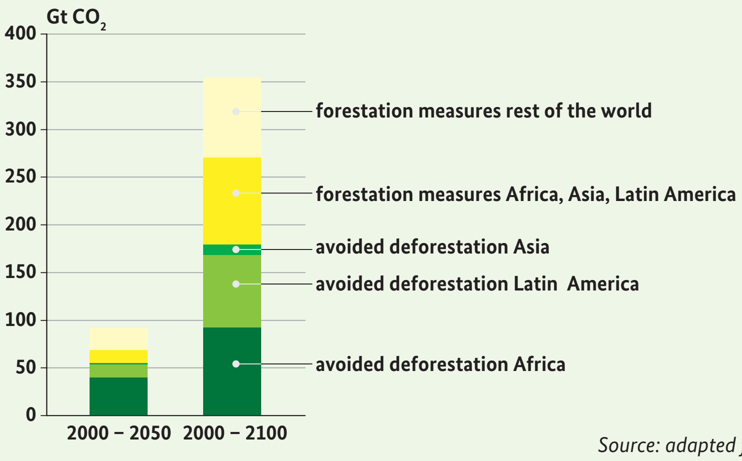
[22] 'Yield gap' describes the difference between crop yields observed at any given location and the crop's potential yield at the same location given current agricultural practices and technologies

The restoration of organic soils (see figures 20 and 21) is the most important mitigation measure connecting agriculture and land use change, although with medium to high restoration costs. The restoration of wetlands increases an important carbon sink, but reduces food production of these highly productive areas.

According to Nabuurs et al. (2007), the carbon mitigation benefits of avoided deforestation are higher than the benefits of afforestation in the medium and long run (see figure 22 and table 10). A sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will therefore generate the largest sustained mitigation benefit.

To develop and implement long-term sustainable forest management requires institutional and human capacity, investment capital and appropriate policies, incentives and international cooperation.

Figure 22 Cumulative mitigation potential avoiding deforestation and promoting reforestation 2000 – 2050 and 2000 – 2100[23]



[23] Values are calculated according to mitigation options under the 2.7 USD/t CO_2 + 5 per cent/year annual carbon price increment.

Source: adapted from Nabuurs et al. 2007 with data from Sathaye et al. 2007

3.2.2 Cropland management, soil and nutrient management and agroforestry

The technical mitigation techniques in cropping systems refer to agronomic practices that allow maximum biomass production on croplands with good soil cover, efficient nutrient management, reduced synthetic nitrogen fertilization, and by caring for optimum growth conditions and carbon sequestration in soils and biomass. These measures highly coincide with climate change adaptation requirements, allowing good synergies for their combined promotion. At farmers level, several adaptation benefits i.e. securing high yields and improving food security and income help promoting the adoption of new techniques.

There are numerous options of GHG mitigation in cropland management, nutrient management, soils and agroforestry. Table 11 gives an overview.

Most of these measures show good synergies between climate change mitigation and adaptation. This is most important, as mitigation alone gives only public benefits, but no direct incentive for farmers. Supportive elements for climate change adaptation refer to increased soil fertility and moisture and favourable cropping conditions that improve the resilience of the cropping system.

Table 11 Crops and farming systems management

Agronomic practices	▸ Increasing yields and crop residues through improved varieties, deep-rooted crops, rotations or mixed crops including perennial species and legumes. ▸ Maintaining biomass production and soil cover throughout the year (avoiding bare soils and rotations with a good balance of production and removal of biomass). ▸ Introducing varieties, which make efficient use of water and available nutrients. ▸ Reducing nitrous oxide emissions through legumes allowing reducing synthetic nitrogen fertilizer or through intermediate cover crops that take up remaining nitrogen.
Nutrient management (fertilisers, crop residues and manure)	▸ Reducing (micro-) nutrient deficiencies for optimum crop growth. ▸ Increasing the efficiency of nitrogen absorption by crops through appropriate dosage and timely application of fertilizers. ▸ Avoiding burning of biomass and crop residues and maintaining maximum biomass in the field for mulching and incorporation. ▸ Improving manure management (compost preparation/manure storage under cover) and per centcapture methane for energy use. ▸ Incorporating of manure and slurry rapidly after application to reduce nitrogen losses.
Soil and tillage management	▸ Reducing soil disturbance resulting in less decomposition with reduced nitrogen emissions and erosion through reduced/no tillage practices (trade off: more herbicide application with no-till). ▸ Avoiding soil compaction through heavy machinery (Gattinger et al. 2011). ▸ Avoiding deep ploughing and maintaining a shallower water table. ▸ Soil and water conservation for improved growth and reduced erosion.
Water management and rice cropping	▸ Avoiding drainage of organic and peaty soils. ▸ Improving water management with controlled draining during the growing seasons (several times) and drying soils during off-growing season can reduce methane production by 60 to 90 per cent (IRRI), however, always combined with good nutrient management since there are trade-offs with nitrous oxide emission especially in soils with high nitrogen saturation. ▸ Using cultivars with low methane exudation rates. ▸ Adjusting timing of residue incorporation and/or composting prior to incorporation (Brown et al. 2012). ▸ Producing biochar from rice straw and husk to avoid GHG during decomposition. ▸ Managing water in flooded rice by alternate drainage (alternate wetting and drying – AWD). ▸ Using the System of Rice Intensification (SRI) with less water consumption and organic fertiliser (climate change adaptation technique), but its mitigation effects are not yet fully known (Gattinger et al. 2011).
Agroforestry and land cover	▸ Increasing carbon stocks through shrubs and trees with more biomass and deep roots, hedges, intercropped rows (but highly variable carbon sequestration results found, Gattinger et al. 2011). ▸ Including cover crops in perennial crop fields, e.g. grass and legumes in orchards and vineyards. ▸ Vegetating of plots of idle land. ▸ Setting aside small spots e.g. unpaved green roads, small lowlands, or creeks.

Current levels of GHG mitigation are far below the nominal technical potential of GHG mitigation. Agricultural policies and extension systems to promote the necessary changes do not yet exist everywhere and do not necessarily work efficiently. Finally, the adoption rate of agricultural measures highly depends on the concomitance of simultaneous positive effects on yield, economic aspects and livelihood strategies.

3.2.3 Mitigation measures for livestock and grazing land management

Livestock and grassland management offer a range of mitigation measures related to improved lifecycle productivity or respecting the specific agronomic site factors when selecting animal species. Reasonable herding with reduced herd sizes and avoiding overgrazing allows grasslands to recover that could be enriched by other root-voluminous crops to maximise carbon storage. Optimum lifecycle management, nutrient cycles and dietary measures can reduce GHG release from livestock raising.

An overview of the most important mitigation measures connected to livestock husbandry and grassland management is shown in table 12.

Table 12 Mitigation measures for livestock and grassland management

Livestock productivity	▸ Increasing livestock productivity within sustainable limits (i.e. milk yield/cow, lifetime efficiency of cows, faster growth of meat animals, esp. when periods with forage shortage, dual purpose animal races for milk and meat, Gattinger et al. 2011). ▸ Increasing ruminant productivity on natural dryland pastures through improved herd and pasture management, breeding, and veterinary services.
Selection of species	▸ Favouring ruminants in pastoral areas with good fodder availability throughout the year. ▸ Favouring monogastric animals (pigs and poultry) instead of (small) ruminants if animal feed from industry waste is available (breweries, ethanol or milling residues).
Increasing grassland productivity	▸ Restoring value to grassland by supporting sound livelihood strategies in extensive grazing areas (Steinfeld 2012). ▸ Managing grazing intensity (stocking rate, rotations and their timing). ▸ Including deep-rooted fodder species and legumes in fodder crops and pastures while reducing synthetic nitrogen fertilizer. ▸ Optimizing nutrient allocation of manure as far as possible (distribution of deposits through spatial herd management and grazing patterns). ▸ Avoiding fires, especially if late and uncontrolled and favouring (fodder) bushes and shrubs on pastures and rangeland.
Longer-term management changes and animal breeding	▸ Optimizing lifecycle of animals to reduce lifetime emissions (favourable ratio between lifetime and product). ▸ Optimizing the balance between grassland and cropland concerning the factors of carbon sequestration, nutrient management and food production. ▸ Optimizing recycling of residues and by-products that can serve for energy production and animal feed (e.g. up to 70 per cent of animal feed in the Netherlands).
Improved feeding practices (ruminants)	▸ Feeding more concentrates to ruminants to improve productivity and reduce enteric methane (even though volatile GHG in manure is increased). ▸ Adding oilseeds to the diet. ▸ Optimising protein intake. ▸ Use of specific dietary additives and agents that reduce methane emissions (halogenated compounds, novel compounds, vaccines against methane-producing bacteria[24].
Manure	▸ Avoiding wet storage of manure, using solid coverage and favour cooling/shading. ▸ Capturing methane emissions for bioenergy use. ▸ Establishing stables or night stands for grazing stock to allow partial collection of manure and urine.

[24] Many dietary additives are still under development and testing, and some have obvious disadvantages, e.g. antibiotics.

3.3 Co-benefits and trade-offs with other development policies

Most of the climate change mitigation measures are at the same time adaptation measures and offer multiple-win opportunities for farmers in developing countries. The co-benefits between climate change mitigation and adaptation measures and other environmental policies are much more important than the trade-offs between them. The international conventions on biodiversity, on combatting desertification and on protecting wetlands comprise numerous actions that contribute to climate change adaptation and mitigation at the same time. Nevertheless, policies that emphasize strongly on increases in agricultural production bear a risk of extending agricultural areas and the utilization of excess nitrogen fertilizers while neglecting climate-smart options. The competition with food security will have to be balanced as far as possible.

Fortunately, the co-benefits between climate change mitigation measures and climate change adaptation and other environmental conventions and policies are much more important than the trade-offs between the different policies. Many of the climate change mitigation measures are at the same time adaptation measures, for example soil organic matter improvement, and thus offer multiple win opportunities, which are interesting for farmers.

The UN-Convention to Combat Desertification (UNCCD) has set regulations to convert croplands to forest and grasslands in vulnerable ecological zones (UNCCD, Smith et al. 2007), which also promotes mitigation. These regulations are implemented in various countries including China. The UNCCD has also set targets towards achieving Zero Net Land Degradation (ZNLD) in the Africa Consensus Statement to Rio+20 (UNCCD 2012).

There are also various measures in the UN-Convention for Biological Diversity (UN-CBD) that also enhance carbon storage as co-benefit. An example is the restoration of conservation zones for wildlife and biodiversity close to lakeshores that benefit the wetland systems in addition.

At the international level, attention is given to enhance the coherence of these environmental conventions and policies. Trade-offs are mainly found between:

- the increasing requirements of food production and bioenergy, which both compete for the limited land resources[25],
- biomass production and biodiversity in case of huge plantations (often feed or biofuel crops) are considered (productivity versus biodiversity),
- setting aside of productive land in industrialized countries causing intensified land use change in developing regions.

The UN Sustainable Development Guidelines had already included indicators for GHG mitigation in 2007 as follows:

- the amount of carbon dioxide and GHG emissions,
- the share of renewable energy sources in total energy use, and
- the energy intensity of transport.

It is important to identify activities with adjacent objectives that generate co-benefits on GHG mitigation allowing more successful mitigation promotion (Smith et al. 2007), for example:

- crop productivity, which reduces total GHG emissions and enhances food security,
- soil carbon increases, which increase soil productivity and prevent land degradation at the same time,
- good water management (leading to increased productivity and efficient use of scarce water resources).

Despite the huge challenge of the growing global population with its requirements on food production, international concepts for food security and

[25] However some exceptions to this competition with regard to bioenergy were found, such as transforming manure into biofuel instead of cutting wood or cropping of bioenergy crops on marginal land, where food crops do not produce on bioenergy contribute effectively to reduce GHG emissions.

climate change consider each other as imperatives, and increasingly link their policies (see chapter 3.1). However, the international discussion hardly refers to family planning to reduce the increase of the global population and its respective food requirements. The UNFCCC scenarios, debates and mitigation concepts (see chapter 3.2) also integrate food security concerns and seek to maximize synergies and minimize trade-offs (CCAFS 2011b). The overlapping objective of increased agricultural productivity gives good reasons for a broad adoption especially of multi-benefit mitigation measures.

The picture becomes more complex with regard to economic development policies and international trade. For instance, the New Partnership for Africa's Development (NEPAD) puts emphasis on agriculturally led development, which besides the increase of productivity often leads to the increase of cropping area (Smith et al. 2007).

The global financial crisis, food price increases and the growing speculation on land as well as 'land grabbing'[26] do not function in favour of climate friendly agriculture. First, priorities tend to shift to the resolution of the immediate crisis at global, national and at household level. Second, the investments in climate friendly activities, which partly pay off only in the future, become scarce and delayed. However, the incentive to produce food crops (instead of energy or feed crops) increases with higher food prices. Conversely, increasing oil prices discourage the transport of agricultural commodities, food products and the use of nitrogen fertilizer as well. The production of biofuel, however, becomes more attractive.

International trade agreements and trade barriers have various effects on the emission of GHG from agriculture. The trade and transport of agricultural commodities has strongly increased in the last two decades. Debt services have rather added to increased international trade, e.g. in South America, where many countries tend to improve their trade balance by agricultural exports to repay their debts. Energy policies and subsidies (e.g. for cooking gas and fuels) also interfere with GHG emissions in various ways, e.g. the reduced use of fuel wood that can contribute to store carbon and reduce pressure on forests and biomass for fuel.

[26] Land speculation and land grabbing are often related to bioenergy production, reducing the consumption of fossil fuel, but increasing the GHG release in the agricultural sector.

3.4 Agricultural mitigation concepts and approaches

> At the international level, the concept of climate smart agriculture concentrates and shapes a number of techniques as elements of already existing agricultural concepts i.e. ecosystem-based approach, eco-agriculture in the light of climate change for both, adaptation and mitigation purposes. It is currently further developed into a more holistic climate smart landscape approach. Other concepts such as organic agriculture also offer good combined adaptation and mitigation solutions. In practice, their mitigation performance compared to conventional production differs according to agro-ecologic factors and farming systems and needs further investigation.

Mitigation concepts for agriculture are largely based on carbon sequestration in soils and biomass and rely on the measures suggested in chapter 3.2. Many of these measures were already included in previous agricultural concepts. Their promotion is likely to be enhanced because of the resulting co-benefits with regard to intensified sustainable production and adaptation (see chapter 3.3) that are necessary for their acceptability.

For instance, the concept of **Climate Smart Agriculture** (CSA), developed as a framework by the FAO (FAO 2013b) in 2010, is widely shared among international organisations (e.g. IFAD[27], World Bank, CGIAR[28]) to simultaneously improve:

- food security and rural livelihoods,
- facilitate climate change adaptation,
- provide mitigation co-benefits.

[27] International Fund for Agricultural Development
[28] Consultative Group on International Agricultural Research

CSA is a holistic concept that includes many widely known land management practices, such as conservation tillage, agroforestry and residue management. These practices were further refined to address mitigation requirements. The recently published Climate Smart Agriculture Sourcebook (FAO 2013b) highlights all climate smart agricultural techniques with a number of case studies in different ecological systems and illustrations.

The CSA concept has recently been enlarged into a climate smart landscapes approach (Scherr et al. 2012). Climate Smart Landscapes (CSL) integrate measures beyond farm scale by adopting an ecosystem approach, working at landscape level, and ensuring intersectoral coordination and cooperation. The concepts of sustainable agriculture and livelihoods are also integral parts of CSL. However, this emerging approach has not yet deployed sufficient efforts to elucidate the mechanisms for its implementation (Scherr et al. 2012). Further similar already known approaches are eco-agriculture, landscape restoration, territorial development, integrated watershed management, agroforestry landscapes, eco-system based approach.

Elements of such integrated agricultural landscape management include:

1. Landscape interventions are designed to achieve multiple objectives including human wellbeing, sustainable food and fibre production, climate change adaptation and mitigation, and conservation of biodiversity and ecosystem services.
2. Ecological, social and economic interactions in different parts of the landscape are managed in order to seek positive synergies among interests and actors or reduce negative trade-offs.
3. The key role of local communities and households as both producers and land stewards is acknowledged.
4. A long-term perspective is taken for sustainable development, adapting strategies as needed to address social and economic changes.
5. Participatory processes of social learning and multi-stakeholder negotiation are institutionalized, and include efforts to involve all parts of the community and ensure that the livelihoods of the most vulnerable people and groups are protected or enhanced.

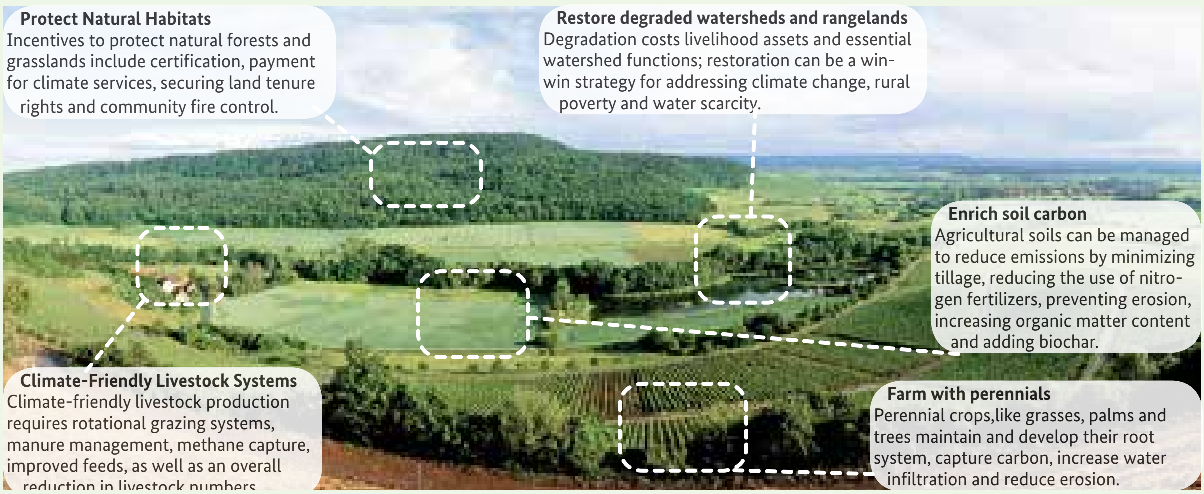
An example of climate smart landscapes with its main elements is shown in figure 23.

The FAO has developed a 'family of climate-smart programmes' in collaboration with other UN organisations in order to improve the capacity of member nations to implement the CSA and CSL measures related to adaptation and mitigation.

The concept of **Organic Agriculture** (OA) is also prominent among the climate friendly agricultural concepts, because the accumulation and conservation of organic matter in soils is a core part of OA. Many of the OA elements are effective for both, mitigation and adaptation. The inherent idea to combine livestock and cropping in OA allows for better local nutrient recycling with less transport, good management of manure and thereby less emission.

According to Gattinger et al. (2011), organic agriculture has proven to increase soil organic carbon at an

Figure 23 Components of a climate smart landscape



Source: adapted from Scherr et al. 2012 average annual rate of 2.2 per cent per year as a result of organic fertilizer use[29]. However, the results differ depending on the initial carbon values in the soils, but also on other environmental characteristics like moisture, temperature and soil type. Niggli et al. (2009) state that organic agriculture can achieve a reduction of 40 per cent of GHG release compared to conventionally managed areas and combined with reduced tillage of even 65 per cent. Similar values of 29 to 37 per cent lower GHG release were also found in other studies (El Hage-Scialabba 2007[30]), because of the omission of synthetic fertilizers and pesticides, and less use of concentrate livestock feed. In practice, yields per area are less in OA in intensive farming regions, but higher in low-input farming systems[31]. However, under intensive farming conditions, GHG emissions in OA / unit of product are often similar or slightly higher compared to conventional agriculture. Methane emissions of ruminants are equal to conventional systems but the increased longevity of organic cattle[32] husbandry counts favourably on methane emissions in OA (except in extensive livestock systems with low productivity). As shown by Muller, the balance of effects for ruminants in OA is positive, if counted on a holistic basis including all aspects in a complex system of feeding practices and land use, longevity and farming systems organisation, the reduction of GHG and other environmental benefits of OA are obvious (Muller et al. 2012).

[29] These high rates might decline after some seasons.

[30] The carbon sequestration efficiency of organic systems in temperate climates is almost double (575 – 700 kg carbon/ha/year) as compared to conventional soils, mainly due to the use of grass clovers for feed and of cover crops in organic crop rotations.

[31] Yields from OA are higher than those from traditional low input systems. However, transforming low input systems into intensified conventional systems would again yield more than by OA. Productivity in organic production systems is management specific. Studies suggest that switching to organic management commonly results in yield reduction in perennial crops of up to 50 per cent, and during the conversion period for high external input systems in areas with favourable crop growth conditions up to 40 per cent. In regions with medium growth conditions and moderate use of synthetic inputs, productivity of organic systems is comparable to conventional systems (92 per cent) and in subsistence agricultural systems, it results in increased yields up to 180 per cent. Overall, the world average organic yields are calculated to be 132 per cent more than current food production levels (Badgley, et al. 2006 in El Hage-Scialabba 2007).

[32] In intensive dairy cattle systems, cows have in average 3 lactation periods only, but up to 5 lactations in organic systems. When considering the rearing period before production, the lifecycle emissions in organic systems are more favourable.

Organic rice production shows a methane release similar to conventional rice production. As in conventional systems, SRI or alternative wetting and drying methods can also reduce methane emissions (up to 22 per cent less, Proyuth 2012).

On a product basis, William found in England a GHG reduction by OA of 2 to 10 per cent for cropping (wheat bread, oil seed rape and potatoes), but a considerable increase of 16 to 46 per cent for animal products such as poultry, eggs and milk (William et al. 2006 in Bellarby et. al. 2008). However, these rather critical results might not be valid for low input conditions as in many developing countries and production systems. Here, in these low input systems, in contrast, the optimization of organic fertilizer and agricultural practices often shows considerable productivity increases compared to conventional agriculture. Thus, the emissions per unit of product are reduced as well.

3.5 Financial compensation mechanisms for climate change mitigation[33]

At the international level, the Kyoto Protocol defined binding obligations for industrialized countries to reduce their GHG emissions and appeals to developing countries to follow in accordance with their development needs. A complex funding system for adaptation and mitigation has been established. The 'Clean Development Mechanism' provides the framework for emission trading with developing countries, in which emission reduction often is less expensive. In addition, the REDD+ program intends to positively influence the forest carbon balance through national programs and actions. The Global Environmental Facility is operational since many years with funding for a wider scope of environmental concerns and a number of other funding sources are either available or under development. In contrast, the progress in international negotiations and agreements has slowed down.

[33] If not marked differently, the information was found on the websites of the UNFCC and the various international funding institutions.

The Kyoto Protocol (KP) to the UN Framework Convention on Climate Change (UNFCCC) sets binding obligations on 37 developed countries (industrialized Annex I countries) to reduce their GHG emissions. It was adopted in 1997 and entered into force in 2005. Until 2011, 192 parties ratified the KP, including almost all UN-member states, except the United States, South Sudan, Andorra, Vatican, and Taiwan. Canada withdrew from the KP in 2011, and Russia, New Zealand and Japan withdrew in 2012. After its first commitment period (2008 to 2012) the KP was extended with new emission targets for the period 2013 to 2020, foreseeing a new post-2012 climate change framework agreement.

Developing countries are actively integrated and are also committed to reducing their emissions without binding targets since 2007, but with an allowance to grow their emissions in consistency with their development needs. At the same time, they receive support for renewable energy, improving energy efficiency and reducing deforestation. This support is mainly directed through the Clean Development Mechanism (CDM), one of the three flexibility mechanisms of the KP in addition to 'international emission trading[34]' and 'joint implementation[35]'.

Clean Development Mechanism of the UNFCCC

The CDM provides a framework for emission reduction on a project basis, which creates Certified Emission Reduction (CER) units that can be traded in emission trading schemes. CDM's two objectives are to assist:

- developing countries (non annex I parties) in achieving sustainable development and in contributing to prevent dangerous climate change, and
- developed countries (annex I parties) in achieving compliance with their quantified emission limitation and reduction commitments.

The mechanism works along a baseline emission situation and seeks to produce emission reductions balanced in a crediting system in favour of developing countries, where emission reductions may be less expensive. An executive board ensures the approval and supervision of CDM projects. 1 billion CER units have been traded through the CDM mechanism between 2001 and 2012. At the initial stage, 46 per cent of the CDM credits referred to the destruction of an industrial gas used in refrigerant systems with rather dubious results[36]. Since 2011, the capture and storage of waste carbon has been integrated into the CDM mechanism[37]. The countries that benefitted from CERs were mainly China (59.9 per cent), India (14.7 per cent), South Korea (9.1 per cent), and Brazil (7.3 per cent). Thus far, least developed countries have not been intensively integrated. The barriers to their integration are related to the limited industrialisation level while natural resources and agriculture are not included in the scheme (except reforestation) or handled in a less advantageous manner, while transaction costs and requirements are relatively high. 2 per cent of this CER volume is channelled into a climate adaptation fund for developing countries (see GEF).

The functioning of the CDM was at risk due to the extremely low carbon price that had fallen from 20 USD/t in 2008 to less than 3 USD/t in 2012, and because of the failure to find an agreement on a new overall Kyoto follow-up protocol during the recent UNFCCC's Conferences of the Parties (COPs).

[34] International emission trading constitutes the framework for a number of regional emission trading schemes such as the oldest and largest 'European Union Emissions Trading System'. It forms a core part of the EU's climate policy and functions according to 'cap and trade' mechanism, where caps are set according to emission goals and allowances for emissions are auctioned. The connection between regional trading schemes towards a global carbon market is (slowly) strengthened, e.g. Australia's trading scheme is about to be linked to the EC's trading scheme.

[35] Annex I (industrialised) countries can invest in emission reducing 'Joint Implementation Projects' in other Annex I countries where emission reduction is cheaper. Countries can herewith lower the costs of achieving their Kyoto targets.

[36] The CDM incentive has driven industrial plants in the developing world to increase the production of gases for air cooling systems (chlorodifluoromethane, known as HCFC-22). A limited number of companies receive huge payments for the destruction of industrial by-products through the CDM mechanism (see also New York Times, 2012). EC has banned this type of support since May 2013.

[37] It is a new option to reduce carbon dioxide emissions in the atmosphere by channelling them into geologically appropriate underground formations and as mineral carbonates. This type of carbon sequestration could achieve significant reductions in huge industrial power plants, but also requires energy for the segregation, channelling, compressing and storage of the gas. The underground storages bear risks of leakages.

In the beginning, among other reasons, the KP excluded the sector agriculture and land use & forestry because of the complexity of measurements and monitoring of carbon fixation. In 2005, the debate was launched, and in 2007 (COP 13 in Bali), an agreement was reached to develop the REDD programme. REDD is independent from the CDM mechanism and is handled by other UN organisations. The debate on its integration into the overall KP mechanisms has not yet been concluded. However, there are a number of risks associated to its integration such as transaction costs, effectiveness, benefits and usufructuaries.

REDD/REDD+ Programme of the United Nations

The UN-REDD Programme is a UN initiative on CO_2 emissions from forest destruction and degradation in developing countries. It was launched in 2008 and builds on the convening role and technical expertise of the FAO, UNDP, and UNEP. It supports nationally-led REDD processes in 46 countries and promotes the informed and meaningful involvement of all stakeholders, including indigenous peoples and other forest-dependent communities in REDD implementation. REDD activities can be undertaken by national or local governments, the private sector and Non-Governmental Organizations (NGOs). REDD+ was recently introduced on the basis of the COP 16 (2011 Cancun) and COP 18 (2012 in Durban). The mechanism includes the sustainable management of forests and the conservation and enhancement of forest carbon stocks. These additions make sure that the quality of forest management, together with its effective carbon stocks is improved.

The REDD+ support works in two ways: either as direct support to the design and implementation of national REDD+ programmes or by complementary support to national REDD+ actions through common approaches, analyses, methodologies, tools, data, and best practices of the UN-REDD Global Programme. REDD+ implementation is always preceded by a strategy design phase. The monitoring uses field inventory data combined with satellite data and available technologies to produce GHG inventories and establish reference emission levels. By July 2012, the total funding to countries was 117.6 million USD.

In 2010, a REDD+ Partnership was formed as an interim body to scale up readiness for REDD and REDD+ actions and to help prepare preparing the incorporation of an effective REDD+ mechanism within a post-2012 climate change agreement (UN-REDD 2011).

REDD works in close cooperation with funding institutions such as the Forest Carbon Partnership Facility (FCPF) and the Forest Investment Programme (FIP), both hosted by the World Bank.

Forest Carbon Partnership Facility (FCPF)

The Forest Carbon Partnership Facility (FCPF) is designed to set the stage for a large-scale system of incentives for the REDD+ programme. FCPF will provide new sources of financing for the sustainable use of forest resources and biodiversity conservation, but also for more than 1.2 billion people, whose livelihoods depend to varying degrees on forests. It will build up REDD capacities in developing countries and assist them in the future in applying REDD incentive systems. In some countries, the FCPF will also help reduce deforestation and forest degradation directly through incentives for the volume of carbon dioxide reduction. The FCPF consists of two separate trust mechanisms, the 'readiness mechanism' and the 'carbon finance mechanism' with the World Bank as a trustee:

- the 'Readiness Mechanism' is currently assisting 37 tropical and sub-tropical developing countries in preparing themselves to participate in a future, large-scale system of positive incentives for REDD including:
  - preparing a REDD strategy and/or complementing the country's existing strategy and policy framework for forest and environmental management, including questions of carbon ownership and benefit-sharing mechanisms,
  - establishing a reference scenario for emissions from deforestation and/or forest degradation, based on recent historical emissions and, possibly, an assessment of future emissions, serving as the reference against which countries will reduce emissions,
  - and establishing a national monitoring, reporting and verification system for emissions and

emission reductions to calculate the reductions in emissions against the reference scenario.

- the 'Carbon Finance Mechanism' is serving countries that have successfully participated in the 'readiness mechanism'. Through this 'Carbon Fund' the FCPF will pilot incentive payments for REDD+ policies and measures. The incentive payments will be guided to various stakeholders, including forest-dependent indigenous peoples, other forest dwellers or the private sector in order to achieve long-term sustainability in financing forest conservation and management programmes.

Climate Investment Funds (CIF)

The Climate Investment Fund (CIF) currently supports 49 countries in climate-resilient development and reduced GHG emissions. At present, it holds the largest fund with 7.6 billion USD and includes four funding mechanisms related to climate change:

- The 'Clean Technology Fund' (CTF) provides developing and middle-income countries with incentives to scale-up the demonstration, deployment, and transfer of technologies with a high potential for long-term GHG emissions savings. CTF focuses on large-scale, country-initiated renewable energy, energy efficiency, and transport projects.
- The 'Pilot Programme for Climate Resilience' (PPCR) helps developing countries to integrate climate resilience into development and offers additional funding to support public and private sector investments. PPCR provides incentives for scaled-up action and initiates a shift from 'business as usual' to broad-based strategies for achieving climate resilience at the national and regional levels.
- The 'Forest Investment Programme' (FIP) supports developing country efforts to reduce deforestation and forest degradation and promote sustainable forest management that leads to emission reductions and enhancement of forest carbon stocks (REDD+). FIP finances large-scale investments and leverages additional resources including the private sector.
- The 'Programme for scaling up renewable energy in low income countries' (SREP) was established to scale-up the deployment of renewable energy solutions and expand renewable markets in the world's poorest countries. SREP aims to pilot and demonstrate the economic, social, and environmental viability of development pathways that do not exacerbate global warming. SREP finances solar, wind, bio-energy, geothermal, and small hydro technologies.

In addition, a Strategic Climate Fund (SCF) serves as an overarching fund to support three targeted programmes (FIP, PPCR, SREP) with dedicated funding to pilot new approaches with potential for scaled-up transformational action aiming at a specific climate change challenge or sectorial response.

Green Climate Fund (GCF)

In 2010, the Green Climate Fund (GCF) was sanctioned at the 16th COP in Cancun in support of the achievement of the objective of the UNFCCC. A transitional committee is currently preparing its definite formation and the main guidelines. In the context of sustainable development, the fund shall promote a paradigm shift towards both, low-emission and climate-resilient development pathways by providing support to developing countries to limit or reduce their GHG emissions and to adapt to climate change impacts, taking into account the needs of those developing countries particularly vulnerable to the adverse effects of climate change.

Global Environment Facility (GEF)

The Global Environment Facility (GEF) was founded in 1991 and includes 183 countries, international institutions, and civil society organisations. As a global public environmental funding institution GEF acts in the areas of biodiversity, climate change, international waters, land degradation, desertification, and other environmental concerns.

GEF is entrusted with the financial mechanism of the UNFCCC on policies, programme priorities and eligibility criteria for funding. It reports annually to the COP and supports the preparation of biennial update reports of developing countries on their emissions. In addition, GEF hosts two other funding mechanisms to support climate change adaptation - the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF).

Thus, a complex funding system for activities connected to forests is already functioning or under preparation. However, climate change mitigation in agriculture is only indirectly included through adaptation measures. In the past, the agricultural sector did not play a prominent role in the UN climate policies. Some progress on the inclusion of agriculture into the debate started in 2009. Agriculture, serving for food security, was not pressurised by carbon reduction targets and is partly considered as a sovereignty right (Murphy et al. 2009). On the operational level, up to now a successful inclusion has been deterred by various constraints, such as:

- a high variety of farming systems, agro-ecosystems and a huge number of farmers, which make the sector very heterogeneous;
- the difficulties to manage measurements of emissions and removals: therefore, reporting will be complex, verification difficult and the variety of sequestration potentials can hardly be assessed correctly; moreover, the limited permanence of carbon sequestration will also have to be taken into account;
- transaction costs are high, when many smallholders are included in the contracts, compared to huge forest areas that can easily be observed even by satellites;
- and there are also doubts from NGOs and other parties whether financial mechanisms of trading agricultural emissions might not foster agribusiness and land grabbing (Gattinger 2011) and disfavour poor rural groups in developing countries.

While little progress has been achieved during the recent COPs, the debate is on-going in a scattered way on various topics:

- on emission trading in agriculture as a topic in preparation of the next protocol, a new definition of the 'land-use sector' is considered that shall include the following activities: agricultural land use, management of pastoral land, grassland and peatland, afforestation, reforestation, and avoided deforestation and degradation according to the IETA (International Emissions Trading Association);
- on restoring value to grasslands, which, according to Steinfeld (2012), shall be developed as a business case for grasslands multiple environmental services and involve carbon finance and other Payments of Environmental Services (PES);
- on working towards zero discharge through the recovery of nutrients and energy from animal manure by zoning to address livestock balance, waste management technology and incentives;
- and on progress attained in countries such as Australia, where agricultural emissions are already included into the trading system, or a few other emission trading systems that are also considering or implementing such systems (Alberta/Canada and New Zealand).

At the same time, the UN system (mainly FAO) has developed other more technical supporting mechanisms and tools for adaptation to and mitigation of climate change:

- FAO-Adapt,
- the Mitigation of Climate Change in Agriculture (MICCA) Program,
- FAO's Forest and Climate Change Programme,
- FAO's Fishery and Aquaculture Climate Change Programme,
- and supporting tools.

3.6 Agricultural mitigation at policy level

An increasing number of countries have formulated 'Nationally Appropriate Mitigation Actions' or 'Low Emission Development Strategies' out of which a considerable number also identifies actions in the agriculture sector. These plans are often well interlinked with other environmental strategies, but many of them show contradictions with agricultural development plans. The progress of their implementation is generally slow. Mitigation activities are not necessarily linked to these documents.

National mitigation policies, NAMA and LEDS

The UNFCCC Copenhagen Conference in 2009 proposed the formulation of Nationally Appropriate Mitigation Actions (NAMA) by countries. In the meantime 55 countries have submitted their NAMAs to the UNFCCC. 21 of the 55 NAMAs propose mitigation actions in the agricultural sector. The International Community allocates 100 billion USD to the implementation of respective mitigation activities. In parallel with NAMAs, a number of countries have formulated Low Emission Development Strategies (LEDS). A detailed framework to draft NAMAs has not been developed. Consequently, the existing NAMAs differ greatly in scope and details. They are currently classified by UNFCCC into two groups: (i) NAMAs seeking support for preparation or for implementation and (ii) those seeking recognition without support. For LEDS, too, common guidelines for their structure and elaboration do not yet exist.

NAMAs and LEDS are usually aligned with the overall national development strategies and consider food security issues and environmental concerns. However, they are often not explicitly linked to agricultural development policies. Several NAMAs are linked to REDD+ objectives, while the proposals do not include many agricultural mitigation measures.

However, the vast majority of mitigation actions in developing countries are neither referred to as LEDS nor NAMAs. (FAO 2013a). In most cases they include mitigation and adaptation at the same time. Policy integration at all levels remains an important challenge. Up to now, agriculture receives a very little portion of the funding for the implementation of NAMAs. The progress towards implementation is rather slow in many countries for a number of reasons. The planning, however, shows interesting results with significant mitigation potential at relatively low costs, which can be achieved in combination with considerable sustainable development benefits.

3.7 Research on climate change mitigation in agriculture

The 'Consultative Group on International Agricultural Research' with its 'Research Programme on Climate Change, Agriculture and Food Security' coordinates the international research with focus on adaptation to climate change, managing climate risk and pro-poor climate change mitigation. The identification of monitoring methods for GHG release in agriculture is under progress.

The Consultative Group on International Agricultural Research (CGIAR) hosts the Research Programme on Climate Change, Agriculture and Food Security (CCAFS). The International Centre leads the CCAFS for Tropical Agriculture (CIAT) in collaboration with the other 14 CGIAR centres. The current portfolio includes four research themes:

- adaptation to progressing climate change,
- adaptation through managing climatic risk,
- integration for decision-making[38], and
- pro-poor climate change mitigation.

It concentrates on mitigation options with a positive impact on livelihoods that therefore have an increased adoption potential. The current programme considers two windows of opportunity (CCAFS 2011c):

- the design of low net emissions agricultural development pathways,
- and the effective capacity of the poor to benefit from carbon financing such as the carbon market.

The research objectives, planned outcomes and outputs of the current 5-year's programme as well as the respective research questions are shown in annex 3.8.

[38] 'Decision-making' refers to the impacts of climate change on food security, the preservation of ecosystem services and the interactions between climate change and other drivers of change in agricultural systems and development.

According to recent information from the Bonn Climate Conference in June 2013, Waldschmidtstraße 4, 60316 Frankfurt am Main [39] two new methods were developed on GHG measurement for smallholders with a landscape approach,

- the Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems (SAMPLES) that aims at creating capacity to analyse the challenges across scales from field to landscape and includes key land users as ultimate decision makers on adoption of mitigation options with a multi-element approach;
- and the Small Holder Agriculture Mitigation Benefit Assessment (SHAMBA), allowing users to investigate current and future environment conditions and land use interventions with the aim to support decision makers seeking options and opportunities for CSA.

All results depend on the quality of data available to feed the model tools. Despite the unresolved data quality limits, they constitute a meaningful step towards the integration of agriculture into carbon trade benefits.

[39] https://unfccc.int/meetings/bonn_jun_2013/meeting/7431.php

4 Conclusions and recommendations

The scope of action for climate change mitigation in agriculture worldwide is vast. The focus of action depends on ecosystems, agro-climatic and agro-economic characteristics and livelihoods in the different regions.

High- and middle-income countries mainly emit GHG emissions in the two sectors of agriculture and land use change. The emissions are particularly important in those countries, where considerable land use change (deforestation in Brazil and Indonesia), and where intensive agricultural activities are carried out (China, India). Although releasing relatively few GHG, low-income countries offer important mitigation potentials in terms of carbon sequestration, which exceed the volume of their emissions.

The international debate on integrating the GHG mitigation of the agricultural sector into global financial compensation mechanisms is progressing slowly. In fact, implementation of mitigation activities in the agricultural sector through carbon credit schemes is very limited so far because

- agriculture is not yet a target sector for public compensation payments,
- first experiences from voluntary carbon payments to agriculture show that the respective transfers are rather small,
- and with prices of around USD 20 t/CO_2 only a limited part of the mitigation potential can be realized while current prices are below even 10 USD/t CO_2.

Mitigation gives only long-term benefits to society and no tangible individual benefits to farmers who practice them at short term. Therefore, mitigation cannot be promoted as a stand-alone objective, neither at farmer's level nor at individual country level. Thus, other incentives are required to ensure widespread and long-term application of mitigation technologies as co-benefits of other adjacent strategies, without depending on compensation payments.

In contrast to mitigation, climate change adaptation provides in most cases considerable direct benefits for farmers such as productivity increases and risk reduction with improved food security and income in consequence. Therefore, mitigation measures should mainly be promoted at farmer's level as co-benefits of adaptation strategies or in connection with other environmental policies such as combatting desertification, preserving biodiversity or protecting wetlands. Considering the challenges in food security, mitigation measures should focus on a maximum of sustainable productivity with a minimum of GHG emissions per product.

Climate friendly agricultural techniques, such as the CSA/CSL concepts developed by the FAO combine climate change mitigation and adaptation on the basis of already existing agricultural concepts. They improve soil fertility and increase the efficiency of water and agricultural input use in order to raise productivity, food security and income or reduce farming risks while improving the overall GHG balance in the production system. The concepts should be promoted as far as possible on a landscape basis (CSL) to foster carbon sequestration and sustainability of the production systems. These mitigation efforts are ideally combined with other environmental strategies to achieve both, environmental and climate objectives in synergy, and immediate benefits to farmers, which will also improve sustainability of the measures.

The highest mitigation opportunities are offered by the land-use sector if forest, range and wetland areas are not transformed into cropping and grazing areas, but instead, are maintained or rehabilitated and capable to sequester additional carbon after afforestation or restoring of rangelands and wetlands. Here mainly communal land is concerned and public benefits are provided in terms of conservation of eco-system services, biodiversity in addition to CO_2 storage. These measures require being formulated, harmonized with other interests, and promoted and sustained as national policies. They involve a limitation of production to existing agricultural lands with a minimum productivity allowing climate friendly and cost-efficient production to serve farmers' needs for food and biomass. Renouncement on agricultural lands might require compensation mechanisms, which could involve the adding of value in terms of productivity to remaining agricultural lands. The CSA/CSL and other concepts would allow such type of melioration with additional productivity increase in many cases and sustainable intensification on the existing agricultural land and improved efficiency of resource use in the agricultural sector as well.

Development cooperation can support GHG mitigation through the following process and areas of support:

1. analysing of GHG emissions in the agricultural and land use sector as well as sequestration potentials at country level and identifying the major mitigation potentials;
2. verifying other development policies and their synergies and trade-offs with the mitigation potentials;
3. formulating combined adaptation and mitigation plans at national level and mainstreaming mitigation interests and potentials into other national policies (combatting desertification, preservation of biodiversity, integrated water resource management, protection or sustainable use of forests and wetlands, energy supply and transport);
4. identifying trade-offs with other policies (agricultural growth and food security) and balancing the competing aspects as far as possible, in particular regarding the discouragement of fertilizer subsidies and the closing of yield gaps in those areas where more food could sustainably be produced, but also searching for alternative livelihood activities for critical areas such as large scale irrigated rice production schemes or marginal production systems with relatively high GHG emissions;
5. transferring the national strategies into local and regional conditions with their respective agro-ecological characteristics and livelihood needs (including fodder and raw materials) with a maximum of participation to ensure adoption;
6. improving capacities of extension services to transfer knowledge and techniques to farmers in the most effective, efficient and sustainable way;
7. identifying gaps, where mitigation potentials are high, but short term benefits for farmers might not be sufficient to adopt new technologies, especially on communal lands, and search for environmental services payments and their availability at the local level;
8. minimizing post-harvest food losses during harvest, storage, transport, processing, preparation and as food waste;
9. working towards the changing of human diets that involve less GHG emissions, e.g. less meat consumption, and
10. last, but very important, foster family planning to reduce future pressure on agricultural land and food production.

The cross-sectoral experience of development cooperation, its long-standing experience in sustainable agricultural and natural resource management concepts and their transfer to specific livelihood and agro-ecological conditions for extension services and farmers could be helpful in many regards.

There might be regional double-win situations in some geographic areas, where other environmental policies might already be under implementation such as the 'Zero Net Land Degradation' and provide at the same time numerous GHG mitigation benefits. In this context, the critical GHG situation of ruminants on marginal grasslands, where alternative livelihoods cannot be identified, might find solutions.

Research and monitoring should continue to identify climate friendly technologies along the production cycle, but also after harvest.

The international debate is mainly focussing on GHG reduction targets in the industrial and energy sector. Global GHG mitigation and climate friendly global governance in the agricultural and land use sectors have to consider food requirements too. If substantial GHG reduction or carbon sequestration services are desired in developing countries with a high burden of projected productivity loss, a debate on a partial shifting of food production to temperate areas with yield gaps and the compensation of carbon sequestration and food deficits for the developing countries should also be launched.

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www.slu.se/Documents/externwebben/centrum-bildningar-projekt/framtidens-lantbruk/Steinfeld%20Uppsala%2029%20March%202012.pdf

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Website information

IRRI, Reducing emissions from rice
http://irri.org/index.php?option=com_k2&view=item&id=9898:reducing-emissions-from-rice&lang=en

Annex 2 Websites of organizations, actors and funding mechanisms

International Organisations

UN .... Online Inventory of the United Nations System Activities on Climate Change
http://www.un.org/climatechange/projectsearch/index.asp

FAO .... Food and Agriculture Organisation
http://www.fao.org/index_en.htm
http://www.fao.org/climatechange/en
http://www.fao.org/climatechange/climatesmart/en

MICCA .... Mitigation of Climate Change in Agriculture Programme (FAO)
http://www.fao.org/climatechange/micca
Global Agenda of Action in support of sustainable livestock sector development (FAO)
http://www.livestockdialogue.org

UNDP .... United Nations Development Fund
http://www.undp.org
http://www.undp.org/content/undp/en/home/ourwork/environmentandenergy/strategic_themes/climate_change

UNEP .... United Nations Environment Program
http://www.unep.org
http://www.unep.org/climatechange

REDD+ .... Reducing Emissions from Deforestation and forest Degradation
http://www.unep.org/climatechange/reddplus/Default.aspx

FCPF .... Forest Carbon Partnership Facility
http://www.forestcarbonpartnership.org

CASCADE .. Carbon Finance for Agriculture, Sylviculture, Conservation and Action against Deforestation
http://www.unep.org/climatechange/mitigation/Agriculture/tabid/104336/Default.aspx

SEF .... Joining Forces to advance public finance for clean energy
http://www.sefalliance.org/english/home.html

FS .... Frankfurt School – UNEP Collaborating Centre for Climate & Sustainable Energy Finance
http://fs-unep-centre.org

UNFCCC ..... UN Framework Convention on Climate Change/Kyoto Protocol
http://unfccc.int/2860.php

CDM .... Clean Development Mechanism
http://cdm.unfccc.int

GEF.............. Global Environment Facility
http://www.thegef.org/gef/home
http://www.thegef.org/gef/climate_change

WB .... World Bank
http://www.worldbank.org
http://climatechange.worldbank.org

CIF .... Climate Investment Funds
https://climateinvestmentfunds.org/cif

Carbon Funds and Facilities at the World Bank
http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCARBONFINANCE/0,,contentMDK:21842339~menuPK:5213558~pagePK:64168445~piPK:64168309~theSitePK:4125853,00.html

WMO .... World Meteorological Organization
http://www.wmo.int/pages/index_en.html

WRI .... World Resources Institute
http://www.wri.org
http://www.wri.org/climate

IPCC .... Intergovernmental Panel on Climate Change
http://www.ipcc.ch

International Research Institutions and Programs

CGIAR .... Consultative Group on International Agricultural Research

CCAFS .... CGIAR Research Program on Climate Change, Agriculture and Food Security

IFPRI .... International Food Policy Research Institute

ILRI .... International Livestock Research Institute

IRRI .... International Rice Research Institute

ICRISAT ..... International Crops Research Institute for the Semi-Arid Tropics

ICARDA ..... International Centre for Agricultural Research in the Dry Areas

CIFOR .... Centre for International Forestry Research

ICRAF .... World Agroforestry Centre

C2ES .... Centre for Climate and energy Solutions

GRISP .... Global Rice Science Partnership

International Scientist Groups

TCG .... Terrestrial Carbon Group
http://www.terrestrialcarbon.org

European Organizations

EC .... European Commission Development and Cooperation – EuropeAid
http://ec.europa.eu/europeaid/index_en.htm

EEA .... European Environment Agency
http://www.eea.europa.eu
http://www.eea.europa.eu/themes/climate

Organizations in Germany

BMEL .... Bundesministerium für Ernährung und Landwirtschaft

BMU .... Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

BMZ .... Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung

UBA .... Umweltbundesamt

GIZ .... Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Other international organizations, instruments and conventions connected to climate change

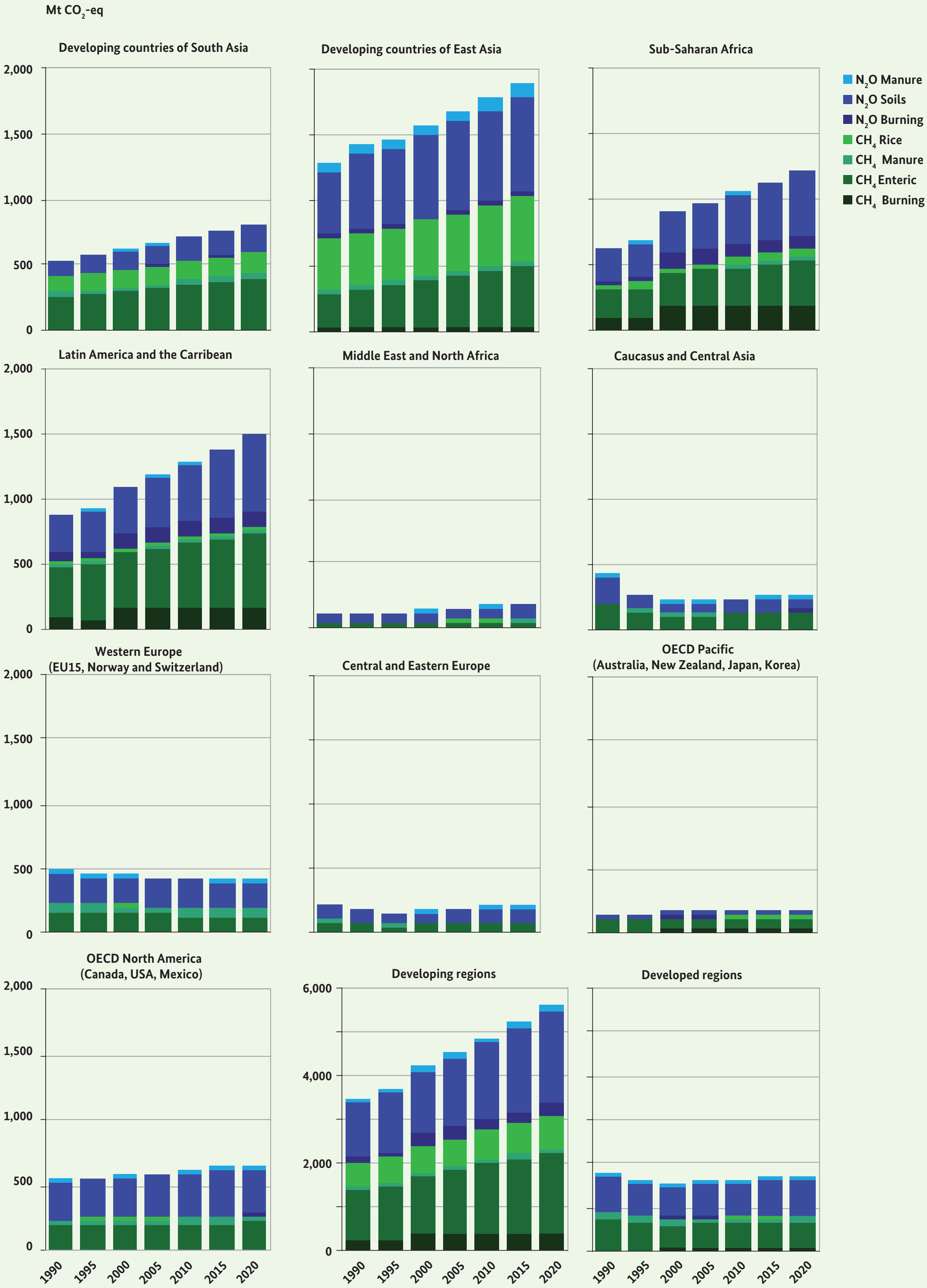
Ramsar Convention on Wetlands
http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__

Convention to Combat Desertification
http://www.unccd.int

Convention on Biological Diversity
http://www.cbd.int

Annex 3 Complementing figures and tables

Annex 3.1 Estimated historical and projected N_2O and CH_4 emissions in the agricultural sector of the ten world regions during the period 1990 – 2020



Source: Smith et al. 2007

Annex 3.2 Emissions from animal excreta and manure management

Annex 3.2.1 Estimated total N_2O emissions from animal excreta in 2004 Nitrous Oxide (N_2O) emissions from manure management after application/ deposition on soil and direct emission

	Dairy cattle	Other cattle	Buffalo	Sheep & goats	Pigs	Poultry	Total
Region/country							
Sub-Saharan Africa	0,06	0,21	0,00	0,13	0,01	0,02	**0,43**
Asia excl. China and India	0.02	0,14	0,06	0,05	0,03	0,05	**0,36**
India	0,03	0,15	0,06	0,05	0,01	0,01	**0,32**
China	0,01	0,14	0,03	0,10	0,19	0,10	**0,58**
Central & South America	0,08	0,41	0,00	0,04	0,04	0,05	**0,61**
West Asia & North Africa	0,02	0,03	0,00	0,09	0,00	0,03	**0,17**
North America	0,03	0,20	0,00	0,00	0,04	0,04	**0,30**
Western Europe	0,06	0,14	0,00	0,07	0,07	0,03	**0,36**
Oceania and Japan	0,02	0,08	0,00	0,09	0,01	0,01	**0,21**
Eastern Europe and CIS	0,08	0,10	0,00	0,03	0,04	0,02	**0,28**
Other developed countries	0,00	0,03	0,00	0,02	0,00	0,00	**0,06**
Total	**0,41**	**1,64**	**0,17**	**0,68**	**0,44**	**0,36**	**3,69**
Livestock Production System							
Grazing	0,11	0,54	0,00	0,25	0,00	0,00	**0,90**
Mixed	0,30	1,02	0,17	0,43	0,33	0,27	**2,52**
Industrial	0,00	0,08	0,00	0,00	0,11	0,09	**0,27**

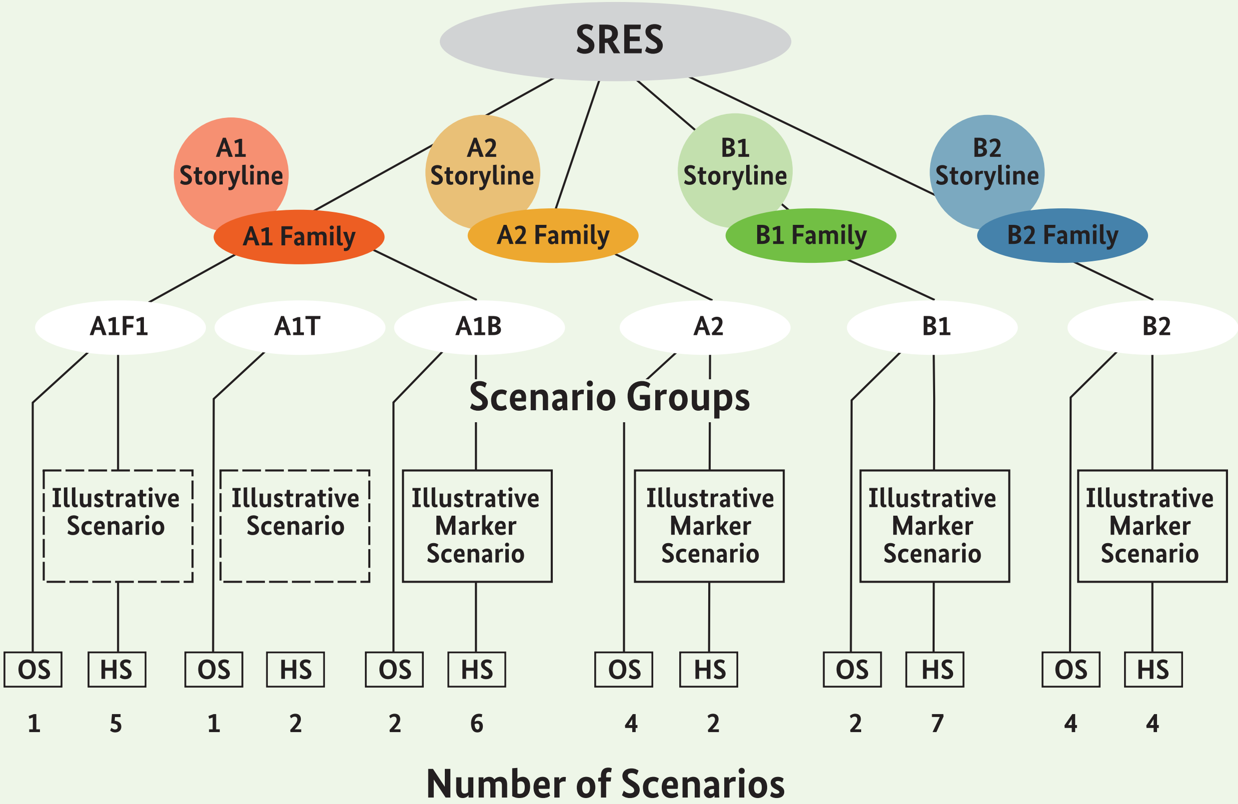
Source: Steinfeld et al 2006

Annex 3.2.2 Estimated global methane emissions from manure management in 2004 (million tons/year)

	Dairy cattle	Other cattle	Buffalo	Sheep & goats	Pigs	Poultry	Total
Region/country							
Sub-Saharan Africa	0,10	0,32	0,00	0,08	0,03	0,04	**0,57**
Asia excl. China and India	0,31	0,08	0,09	0,03	0,50	0,13	**1,14**
India	0,20	0,34	0,19	0,04	0,17	0,01	**0,95**
China	0,08	0,11	0,05	0,05	3,43	0,14	**3,84**
Central & South America	0,10	0,36	0,00	0,02	0,74	0,19	**1,41**
West Asia & North Africa	0,06	0,09	0,01	0,05	0,00	0,11	**0,32**
North America	0,52	1,05	0,00	0,00	1,65	0,16	**3,39**
Western Europe	1,16	1,29	0,00	0,02	1,52	0,09	**4,08**
Oceania and Japan	0,08	0,11	0,00	0,03	0,10	0,03	**0,35**
Eastern Europe and CIS	0,46	0,65	0,00	0,01	0,19	0,06	**1,38**
Other developed countries	0,01	0,03	0,00	0,01	0,04	0,02	**0,11**
Total	**3,08**	**4,41**	**0,34**	**0,34**	**8,38**	**0,97**	**17,52**
Livestock Production System							
Grazing	0,15	0,50	0,00	0,12	0,00	0,00	**0,77**
Mixed	2,93	3,89	0,34	0,23	4,58	0,31	**12,27**
Industrial	0,00	0,02	0,00	0,00	3,80	0,67	**4,48**

Source: Steinfeld et al 2006

Annex 3.3 **Main characteristics of the four SRES storylines and scenario families**



Schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called ‘families’: A1, A2, B1, and B2. Altogether 40 SRES scenarios have been developed by six modeling teams. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Within each family and group of scenarios, some share ‘harmonized’ assumptions on global population, gross world product, and final energy. These are marked as ‘HS’ for harmonized scenarios. ‘OS’ denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios. The number of scenarios developed within each category is shown. For each of the six scenario groups an illustrative scenario (which is always harmonized) is provided. Four illustrative marker scenarios, one for each scenario family, were used in draft form in the 1998 SRES open process and are included in revised form in this Report. Two additional illustrative scenarios for the groups A1FI and A1T are also provided and complete a set of six that illustrates all scenario groups. All are equally sound.

By 2100 the world will have changed in ways that are difficult to imagine – as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key ‘future’ characteristics such as demographic change, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends.

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).*

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid- century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more dive.

* Balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

Source: IPCC 2000. Special Report on Emission Scenarios – Summary for Policy Makers

Annex 3.4 Annual mitigation potentials in four climatic regions (non-livestock)

			CO_2 (t CO_2/ha/yr)			CH_4 (t CO_2-eq/ha/yr)			N_4O (t CO_2-eq/ha/yr)			All GHG (t CO_2-eq/ha/yr)		
Climate zone	**Activity**	**Practice**	**Mean estimate**	**Low**	**High**	**Mean estimate**	**Low**	**High**	**Mean estimate**	**Low**	**High**	**Mean estimate**	**Low**	**High**
Cool-dry	Croplands	Agronomy	0.29	0.07	0.51	0.00	0.00	0.00	0.10	0.00	0.20	0.39	0.07	0.71
	Croplands	Nutrient management	0.26	-0.22	0.73	0.00	0.00	0.00	0.07	0.01	0.32	0.33	-0.21	1.05
	Croplands	Tillage and residue management	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
	Croplands	Water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	Set-aside and LUC	1.61	-0.07	3.30	0.02	0.00	0.00	2.30	0.00	4.60	3.93	-0.07	7.90
	Croplands	Agro-forestry	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
	Grasslands	Grazing, fertilization, fire	0.11	-0.55	0.77	0.02	0.01	0.02	0.00	0.00	0.00	0.13	-0.54	0.79
	Organic soils	Restoration	36.67	3.67	69.67	-3.32	-0.05	-15.30	0.16	0.05	0.28	33.51	3.67	54.65
	Degraded lands	Restoration	3.45	-0.37	7.26	0.08	0.04	0.14	0.00	0.00	0.00	3.53	-0.33	7.40
	Manure/biosolids	Application	1.54	-3.19	6.27	0.00	0.00	0.00	0.00	-0.17	1.30	1.54	-3.36	7.57
	Bioenergy	Soils only	0.15	-0.48	0.77	0.00	0.00	0.00	0.02	-0.04	0.09	0.17	-0.52	0.86
Cool-moist	Croplands	Agronomy	0.88	0.51	1.25	0.00	0.00	0.00	0.10	0.00	0.20	0.98	0.51	1.45
	Croplands	Nutrient management	0.55	0.01	1.10	0.00	0.00	0.00	0.07	0.01	0.32	0.62	0.02	1.42
	Croplands	tillage and residue management	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
	Croplands	Water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	Set-aside and LUC	3.04	1.17	4.91	0.02	0.00	0.00	2.30	0.00	4.60	5.36	1.17	9.51
	Croplands	Agro-forestry	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
	Grasslands	Grazing, fertilization, fire	0.81	0.11	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.11	1.50
	Organicsoils	Restoration	36.67	3.67	69.67	-3.32	-0.05	-15.30	0.16	0.05	0.28	33.51	3.67	54.65
	Degraded lands	Restoration	3.45	-0.37	7.26	1.00	0.69	1.25	0.00	0.00	0.00	4.45	0.32	8.51
	Manure/biosolids	Application	2.79	-0.62	6.20	0.00	0.00	0.00	0.00	-0.17	1.30	2.79	-0.79	7.50
	Bioenergy	Soils only	0.51	0.00	1.03	0.00	0.00	0.00	0.02	-0.04	0.09	0.53	-0.04	1.12
Warm-dry	Croplands	Agronomy	0.29	0.07	0.51	0.00	0.00	0.00	0.10	0.00	0.20	0.39	0.07	0.71
	Croplands	Nutrient management	0.26	-0.22	0.73	0.00	0.00	0.00	0.07	0.01	0.32	0.33	-0.21	1.05
	Croplands	Tillage and residue management	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
	Croplands	Water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	Set-aside and LUC	1.61	-0.07	3.30	0.02	0.00	0.00	2.30	0.00	4.60	3.93	-0.07	7.90
	Croplands	Agro-forestry	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
	Grasslands	Grazing, fertilization, fire	0.11	-0.55	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.11	-0.55	0.77
	Organic soils	Restoration	73.33	7.33	139.33	-3.32	-0.05	-15.30	0.16	0.05	0.28	70.18	7.33	124.31
	Degraded lands	Restoration	3.45	-0.37	7.26	0.00	0.00	0.00	0.00	0.00	0.00	3.45	-0.37	7.26
	Manure/biosolids	Application	1.54	-3.19	6.27	0.00	0.00	0.00	0.00	-0.17	1.30	1.54	-3.36	7.57
	Bioenergy	Soils only	0.33	-0.73	1.39	0.00	0.00	0.00	0.02	-0.04	0.09	0.35	-0.77	1.48
Warm-moist	Croplands	Agronomy	0.88	0.51	1.25	0.00	0.00	0.00	0.10	0.00	0.20	0.98	0.51	1.45
	Croplands	Nutrient management	0.55	0.01	1.10	0.00	0.00	0.00	0.07	0.01	0.32	0.62	0.02	1.42
	Croplands	Tillage and residue management	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89
	Croplands	Water management	1.14	-0.55	2.82	0.00	0.00	0.00	0.00	0.00	0.00	1.14	-0.55	2.82
	Croplands	Set-aside and LUC	3.04	1.17	4.91	0.02	0.00	0.00	2.30	0.00	4.60	5.36	1.17	9.51
	Croplands	Agro-forestry	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89
	Grasslands	Grazing, fertilization, fire	0.81	0.11	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.81	0.11	1.50
	Organic soils	Restoration	73.33	7.33	139.33	-3.32	-0.05	-15.30	0.16	0.05	0.28	70.18	7.33	124.31
	Degraded lands	Restoration	3.45	-0.37	7.26	0.00	0.00	0.00	0.00	0.00	0.00	3.45	-0.37	7.26
	Manure/biosolids	Application	2.79	-0.62	6.20	0.00	0.00	0.00	0.00	-0.17	1.30	2.79	-0.79	7.50
	Bioenergy	Soils only	0.70	-0.40	1.80	0.00	0.00	0.00	0.02	-0.04	0.09	0.72	-0.44	1.89

Notes:

The estimates represent average change in soil carbon stocks (CO_2) or emissions of N_2O and CH_4 on a per hectare basis. Positive values represent CO_2 uptake which increases the soil carbon stock, or a reduction in emissions of N_2O and CH_4.

Estimates of soil carbon storage (CO_2 mitigation) for all practices except management of organic soils were derived from about 200 studies (see IPCC, 2006, Grassland and Cropland Chapters of Volume IV, Annexes 5A and 6A) using a linear mixed-effect modelling approach, which is a standard linear regression technique with the inclusion of random effects due to dependencies in data

from the same country, site and time series (Ogle et al., 2004, 2005; IPCC, 2006; Smith et al., 2007b). The studies were conducted in regions throughout the world, but temperate studies were more prevalent leading to smaller uncertainties than for estimates for warm tropical climates. Estimates represent annual soil carbon change rate for a 20-year time horizon in the top 30 cm of the soil.

Soils under bio-energy crops and agro-forestry were assumed to derive their mitigation potential mainly from cessation of soil disturbance, and given the same estimates as no-till. Management of organic soils was based on emissions under drained conditions from IPCC guidelines (IPCC, 1997). Soil CH_4 and N_2O emission reduction potentials were derived as follows:

a. for organic soils, N_2O emissions were based on the median, low and high nutrient status organic soil N_2O emission factors from the IPCC GPG LULUCF (IPCC, 2003) and CH_4 emissions were based on low, high and median values from Le Mer and Roger (2001);

b. N_2O figures for nutrient management were derived using the DAYCENT simulation model, and include both direct emissions from nitrification/denitrification at the site, as well as indirect N_2O emissions associated with volatilization and leaching/runoff of N that is converted into N_2O following atmospheric deposition or in waterways, respectively (US-EPA, 2006b; assuming a N reduction to 80 per cent of current application);

c. N_2O figures for tillage and residue management were derived using DAYCENT (US-EPA, 2006b; figures for no till);

d. Rice figures were taken directly from US-EPA (2006b) so are not shown here. Low and high values represent the range of a 95 per cent confidence interval. Table 8.4 has mean and uncertainty for change in soil C, N_2O and CH_4 emissions at the climate region scale, and are not intended for use in assessments at finer scales such as individual farms.

Source: Smith et al. 2007

Annex 3.5 Technical forest mitigation potential

Potential of mitigation measures of global forestry activities. Global model results indicate annual amount sequestered or emissions avoided, above business as usual, in 2030 for carbon prices 100 USD/tCO_2 and less.

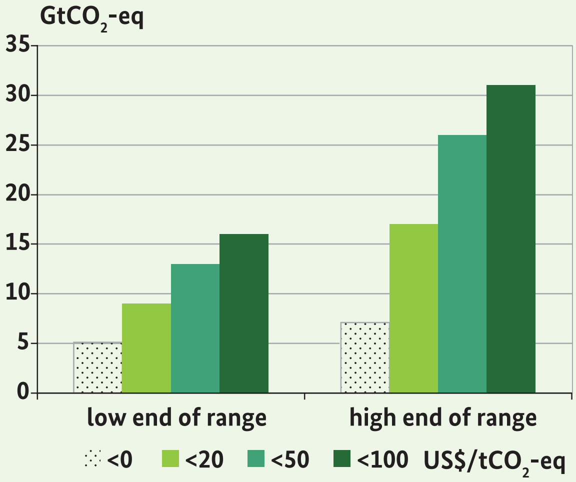
Region	Activity	Potential at costs equal or less than 100 USD/tCO_2, in $MtCO_2$/yr in 2030 *	Fraction in cost class: 1 – 20 USD/tCO_2	Fraction in cost class: 20 – 50 USD/tCO_2
USA	Afforestation	445	0.3	0.3
	Reduced deforestation	10	0.2	0.3
	Forest management	1,590	0.26	0.32
	TOTAL	2,045	0.26	0.31
Europe	Afforestation	115	0.31	0.24
	Reduced deforestation	10	0.17	0.27
	Forest management	170	0.3	0.19
	TOTAL	295	0.3	0.21
OECD Pacific	Afforestation	115	0.24	0.37
	Reduced deforestation	30	0.48	0.25
	Forest management	110	0.2	0.35
	TOTAL	255	0.25	0.34
Non-annex East Asia	Afforestation	605	0.26	0.26
	Reduced deforestation	110	0.35	0.29
	Forest management	1,200	0.25	0.28
	TOTAL	1,915	0.26	0.27
Countries in transition	Afforestation	545	0.35	0.3
	Reduced deforestation	85	0.37	0.22
	Forest management	1,055	0.32	0.27
	TOTAL	1,685	0.33	0.28
Central and South America	Afforestation	750	0.39	0.33
	Reduced deforestation	1,845	0.47	0.37
	Forest management	550	0.43	0.35
	TOTAL	3,145	0.44	0.36
Africa	Afforestation	665	0.7	0.16
	Reduced deforestation	1,160	0.7	0.19
	Forest management	100	0.65	0.19
	TOTAL	1,925	0.7	0.18
Other Asia	Afforestation	745	0.39	0.31
	Reduced deforestation	670	0.52	0.23
	Forest management	960	0.54	0.19
	TOTAL	2,375	0.49	0.24
Middle East	Afforestation	60	0.5	0.26
	Reduced deforestation	30	0.78	0.11
	Forest management	45	0.5	0.25
	TOTAL	135	0.57	0.22
TOTAL	Afforestation	4,045	0.4	0.28
	Reduced deforestation	3,950	0.54	0.28
	Forest management	5,780	0.34	0.28
	TOTAL	13,775	0.42	0.28

* Results average activity estimates reported from three global forest sector models including GTM (Sohngen and Sedjo, 2006), GCOMAP (Sathaye et al., 2007), and IIASA-DIMA (Benitez-Ponce et al., 2007). For each model, output for different price scenarios has been published. The original authors were asked to provide data on carbon supply under various carbon prices. These were summed and resulted in the total carbon supply as given middle column above. Because carbon supply under various price scenarios was requested, fractionation was possible as well.

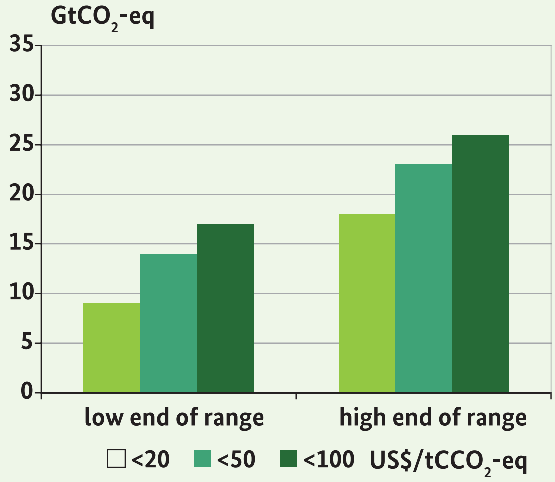
Two right columns represent the proportion available in the given cost class. None of the models reported mitigation available at negative costs. The column for the carbon supply fraction at costs between 50 and 100 USD/tCO_2 can easily be derived as 1- sum of the two right hand columns.

Source: Nabuurs et al. 2007

Annex 3.6 Global economic mitigation potential in 2030 estimated from bottom-up and top-down studies



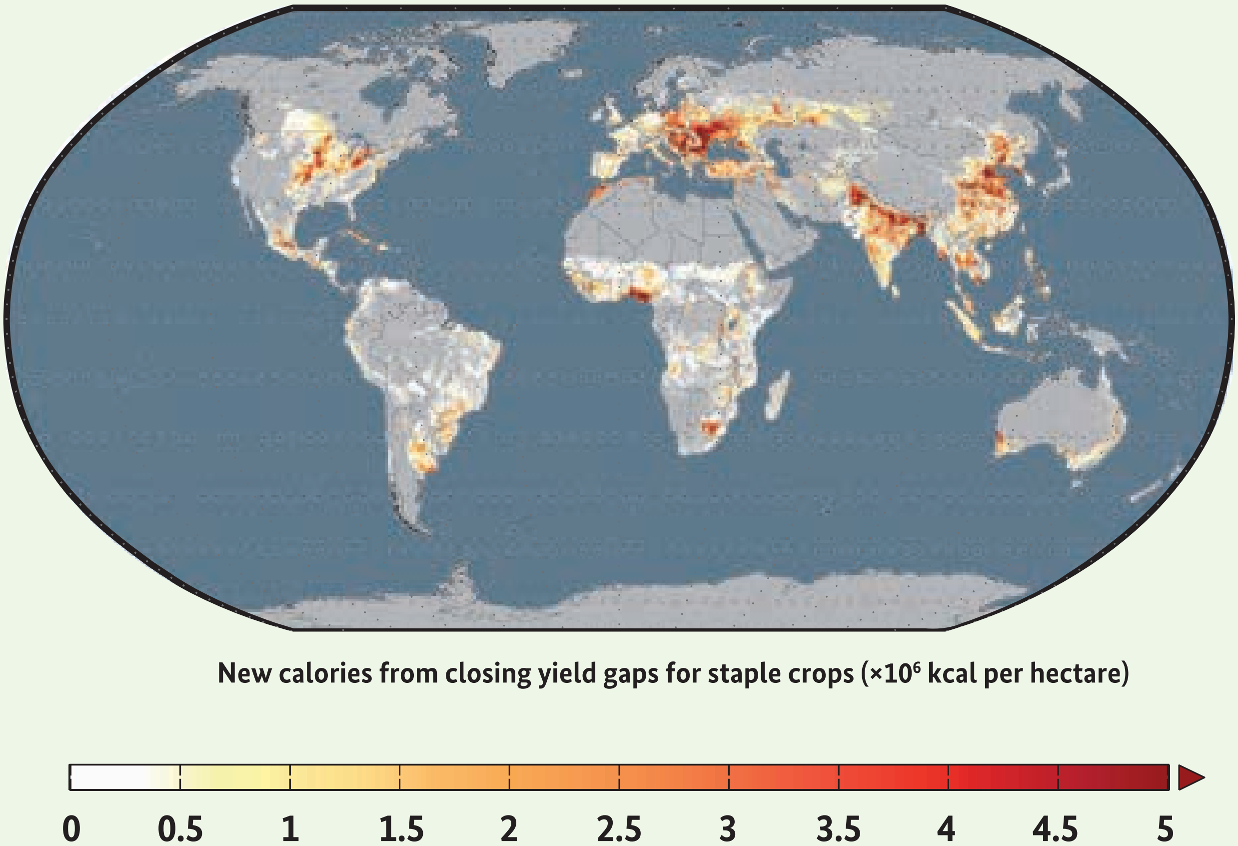
Global economic mitigation potential in 2030 estimated from bottom-up studies



Global economic mitigation potential in 2030 estimate from top-down studies

Source: adapted from IPCC 2007

Annex 3.7 Additional calories from closing yield gaps for staple crops



Closing global yield gaps. Many agricultural lands do not attain their full yield potential. The figure shows the new calories that would be made available to the world from closing the yield gaps for 16 major crops: barley, cassava, groundnut, maize, millet, potato, oil palm, rapeseed, rice, rye, sorghum, soybean, sugar-beet, sugarcane, sunflower and wheat. This analysis shows that bringing the world's yields to within 95 per cent of their potential for these 16 important food and feed crops could add 2.3 billion tonnes (5 x 1,015 kilocalories) of new crop production, representing a 58 per cent increase. These improvements in yield can be largely accomplished by improving the nutrient and water supplies to crops in low-yielding regions; further enhancement of global food production could be achieved through improved crop genetics. The methods used to calculate yield gaps and limiting factors are described in the Supplementary Information.

Source: Foley et al. 2011

Annex 3.8 CCAFS mitigation research objectives and research questions

CCAFS research objectives, outcomes and outputs of pro poor climate change mitigation

Objectives	Outcomes	Outputs
Objective 1 Inform decision makers about the impacts of alternative agricultural development pathways	**Outcome 1.1** Enhanced knowledge about agricultural development pathways that lead to better decisions for climate mitigation, poverty alleviation, food security and environmental health, used by national agencies in at least 20 countries	**Output 1.1.1** Analysis of agricultural development pathways and the trade-offs among mitigation, poverty alleviation, food security and environmental health **Output 1.1.2** Enhanced tools, data and analytic capacity in regional and national policy and research organizations to analyse the implications of different development scenarios and mitigation strategies **Output 1.1.3** Analysis of the gender and social differentiation implications of alternative agricultural
Objective 2 Identify institutional arrangements and incentives that enable smallholder farmers and common-pool resource users to reduce GHGs and improve livelihoods	**Outcome 1.2** Improved knowledge about incentives and institutional arrangements for mitigation practices by resource-poor smallholders (including farmers' organizations), project developers and policy makers in at least 10 countries	**Output 1.2.1** Evidence, analysis and trials to support institutional designs, policy and finance that will deliver benefits to poor farmers and women, and reduce GHG emissions **Output 1.2.2** Improved capacity to increase the uptake and improve the design of incentives mechanisms and institutional arrangements to deliver benefits to poor farmers and women
Objective 3 Test and identify desirable on-farm practices and their landscape-level implications	**Outcome 1.3** Key agencies dealing with climate mitigation in at least 10 countries promoting technically and economically feasible agricultural mitigation practices that have eo-benefits for resource-poor farmers, particularly vulnerable groups and women	**Output 1.3.1** Analysis of mitigation biophysical and socio-economic feasibility for different agricultural practices and regions, and impacts on emissions, livelihoods and food security **Output 1.3.2** Methods developed and validated for GHG monitoring and accounting at farm and landscape level to contribute to compliance and voluntary market standards **Output 1.3.3** Synthesis of understanding about the direct and indirect economic and environmental costs and benefits from agricultural mitigation **Output 1.3.4** Analysis of impacts of on-farm and landscape level practices on women and poor farmers

Source: adapted from CCAFS (2011c)

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