Potentials for Greenhouse Gas Mitigation in Agriculture

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

Published by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Friedrich-Ebert-Allee 40
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E naren@giz.de
I www.giz.de/sustainable-agriculture

Sector Project Sustainable Agriculture (NAREN)

Author
UNIQUE forestry and land use GmbH, Freiburg, Germany

Design/layout
Ira Olaleye, Eschborn, Germany

Photo credits/sources:
Pg. 8: ©GIZ/Bärbel Högner; Pg. 38: ©GIZ/Elmar Foellmi; Pg. 50: ©GIZ/Dirk Ostermeier; Pg. 58: ©GIZ/Andreas König; all other photos incl. cover: ©Birgit Kundermann

On behalf of
German Federal Ministry for Economic Cooperation and Development (BMZ)
Division Rural development; agriculture; food security

GIZ is responsible for the content of this publication.

Printing and distribution:
Druckreif gmbH, Frankfurt

Printed on 100% recycled paper, certified to FSC standards.

Revised edition, April 2018
First Edition 2014

Content

List of figures

List of tables

List of info boxes

Abbreviations and acronyms

AFOLU	Agriculture, forestry and land use
AWD	Alternate Wetting and Drying
BMZ	*Bundesministerium für Entwicklung und Zusammenarbeit*, German Federal Ministry for Development Cooperation
CDM	Clean Development Mechanism
CIF	Climate Investment Funds
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COMPACI	Competitive African Cotton Initiative
DFI	Development finance institutions
FIP	Forest Investment Programme
FLW	Food losses and waste
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse gas
GWP	Global warming potential
IFC	International Finance Corporation
IIC	Inter-American Investment Corporation
IPCC	Intergovernmental Panel on Climate Change
KCCAP	Kenya Climate Change Action Plan
KTDA	Kenya Tea Development Agency
M&E	Monitoring and Evaluation
MRV	Monitoring, reporting and verification
N_2O	Nitrous oxide
NAMAs	Nationally Appropriate Mitigation Actions
NYDF	New York Declaration on Forests
PPCR	Pilot Programme for Climate Resilience
REDD+	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SOC	Soil organic carbon
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

Agriculture alone contributes 10–12% to global greenhouse gas emissions, while at the same time being severely affected by climate change. A growing world population and changing diets put additional pressure on already scarce productive resources.

The international climate policy discussion related to agriculture and food production is mainly focusing on adaptation and increased resilience. However, the perception is slowly shifting towards including mitigation as well, first and foremost in industrialized countries but also in emerging economies, where emissions are relatively high. Many mitigation interventions are at the same time adaptation measures (and vice versa) and can generate economic benefits by increasing or stabilizing yields, cutting production costs and improving climate risk adjusted returns. These economic benefits, if quantifiable and proven, make it more likely for producers to invest in mitigation measures. Whenever mitigation interventions are planned and implemented, those with multiple social, environmental and economic benefits have the greatest adoption potential.

The report presents an overview of the most relevant agricultural GHG emissions following the Intergovernmental Panel on Climate Change (IPCC) logic. The most important emissions categories are enteric fermentation (digestion process of ruminants e.g. cattle, sheep, goats etc.), manure left on pasture, synthetic fertilizers, rice cultivation, manure management, and burning of savannas. Additional emissions come from forestry and land use change, primarily due to deforestation and transformation of forests and savannahs into pasture and cropland. The relevance of emissions categories as well as projected future trends vary greatly by global region.

Agricultural emissions refer mainly to the production stage (i.e. on farm). Upstream and downstream emissions can be substantial however but they are not singled out for the agricultural sector. Reducing loss and waste in food value chains is the most promising area of intervention to achieve higher value chain efficiencies, but the potential for efficiency improvements are large at various stages of the global agricultural value chains. Area, input and energy efficiency as well as reduced food loss and waste allow decreased emissions intensity per unit of end product, despite possible higher emissions from the entire system. Efficiency accounting will be part of the solution in promoting mitigation in agriculture.

Mitigation in agriculture cannot be seen in isolation, since interlinkages to other land use sectors as well as transport and energy are numerous and complex. The concept of landscape restoration encompasses a holistic approach and has the potential to bring the different relevant stakeholders together.

Conserving wetlands and forest lands, while sustainably producing on favourable agricultural soils has the main mitigation potential in the agricultural sector and is more cost-efficient than restoring degraded lands that were never indicated for agricultural production. Sustainable intensification on existing agricultural land and application of good practices are therefore important measures to avoid further degradation.

Emerging economies are more essential than least developed countries in terms of agricultural mitigation potential and strategies should be tailored to specific country circumstances. The affluent urban community requires support to educate the young generation on healthy diets and a better understanding of the environmental consequences of certain forms of food production to increase the demand sustainably produced food.

The private sector is a logical partner in agricultural mitigation due to topics such as deforestation free value chains, efficiency investments in processing as well as sustainable sourcing from farms "upstream" in their value chains. These private actors have a different set of expertise and a network of producers and suppliers that can complement target groups of development cooperation programs and vice versa.

So far, there are no overarching studies on the economic benefits of mitigation practices by region, commodity and typical farm size. Anecdotal information exists on selected production systems but more in-depth information is needed in order to prove the business case of mitigation measures at farm level in site-specific contexts.

Demand side measures have not been part of the agricultural mitigation discussion so far, although they represent a large mitigation potential. Measures targeted at consumers in industrialized countries as well as affluent populations in emerging economies and developing countries are often seen as politically sensitive. Reducing food loss and waste is therefore a promising entry point in mitigation. It requires strong alignment of food related trade and retail regulations with private sector action. Due to efficiency gains, there might be a promising business case for companies to invest in such measures.

The study has been commissioned by the GIZ Sector Project Sustainable Agriculture (SV 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 provide information to the international discussion about the climate change mitigation potentials of the agricultural sector and associated land-use change.

1

Background

The importance of agricultural mitigation within the global development context receives growing recognition. Agriculture is a major emitter of greenhouse gas emissions (GHGs) while at the same time being severely affected by climate change. A growing world population and changing diets put additional pressure on already scarce productive resources. More efficient production in terms of GHG output per unit produced is a key aspect in agricultural mitigation, as overall agricultural emissions are likely to grow as economies and populations develop.

The international climate policy discussion related to agriculture and food production is mainly focusing on adaptation and increased resilience. However, the perception is slowly shifting towards including mitigation as well, first and foremost in industrialized countries but also in emerging economies. Public and private investments in agriculture with climate co-benefits (either adaptation or mitigation) are mainly focusing on mitigation. This is due to the fact that clean energy investments dominate this space. At the same time, the private sector has overtaken public donors as the main investors in projects with climate co-benefit across sectors. This points to a policy-investment divide that represents great potential to a) bring mitigation from the energy and private sector sphere into the land use discussion; and b) for getting private investors also on board for mitigation investments in agriculture and forestry.

Many mitigation interventions are at the same time adaptation measures (and vice versa) and generate economic benefits as they increase yields, cut production costs and improve climate risk adjusted returns. Improved soil management for example increases the soil carbon content and therefore plant productivity. Water efficiency investments save freshwater and reduce irrigation related emissions and costs for water pumping. These economic benefits, if quantifiable and proven, make it more likely for producers to invest in mitigation measures. Current technical adoption barriers have to be addressed through technical assistance. Private sector investments have to be mobilized for mitigation investments by reducing technical risks and demonstrating the business case.

Other environmental benefits such as biodiversity improvements (in the soil or through planted trees) and social co-benefits (job creation, diversification of income, etc.) of mitigation measures can be substantial. Whenever mitigation interventions are planned and implemented, those with multiple benefits have the greatest adoption potential.

2

GHG emissions in agriculture and land use change

2.1 General overview and main trends

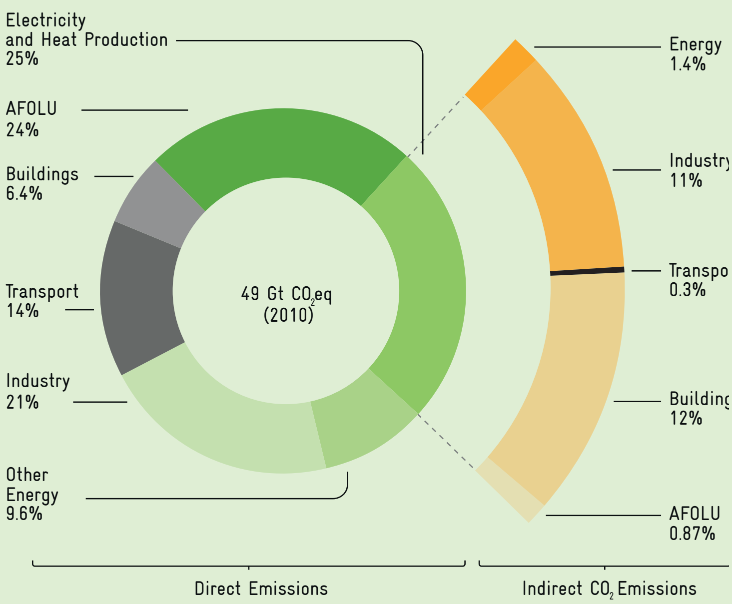
The Intergovernmental Panel on Climate Change (IPCC) divides greenhouse gas (GHG) emissions into seven sectors (figure 1). At the global level, electricity and heat production together with other energy is the most important emission source (34.6%) followed by agriculture, forestry and other land-use (AFOLU) with 24% and industry with 21%.[1]

The release of emissions largely differs throughout the world according to the income level of countries (Figure 2). The highest share of emissions still comes from high income countries (18.7 GtCO_2e), e.g. USA and Germany. However, their emissions are stagnant with an increase of only 0.4 GtCO_2e since 1990. Nearly the same amount of emissions today comes from the group of Upper Middle Income countries (18.3 GtCO_2e) (e.g. China, Brazil and the Russian Federation), which have nearly doubled their emissions since 1990. The other three groups together emit only 12.4 GtCO_2e representing 25% of the 49 GtCO_2e global emissions.

Wealthier countries emit higher per capita quantities of GHG than poorer countries. However, some countries that are large emitters in absolute terms can have relatively low per capita emissions (e.g. China, India), whereas others can have high per capita emissions but contribute a relatively small share of absolute global emissions e.g. Qatar, United Arab Emirates (FAO 2015).

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

Greenhouse Gas Emissions by Economic Sectors



Source: adapted from Smith et al. 2014

[1] The 0.87% AFOLU emissions under energy consist mainly of CO2 and minor emission of methane and nitrous oxide produced by fossil fuel burning for machinery, power irrigation, and fishing vessels. Estimates include emissions by main energy carriers: gas-diesel oils, gasoline, natural gas (including liquefied natural gas), liquefied petroleum gas, residual fuel oil, hard coal and electricity (Tubiello et al. 2014).

The share of emissions from AFOLU is low in wealthier countries, where the energy, industry and transport sectors are high emitters. Poorer countries have a high share of AFOLU emissions as they depend largely on the primary sector (Smith et al. 2014).

In contrast to the energy, industry and transport sectors, AFOLU does not display a globally rising trend because a growing number of countries adopt policies that lead to better protection of forests, higher productivity in agriculture reducing pressure to convert natural forests to cropland, and a restoration of previously degraded lands (Ausubel et al., 2013).

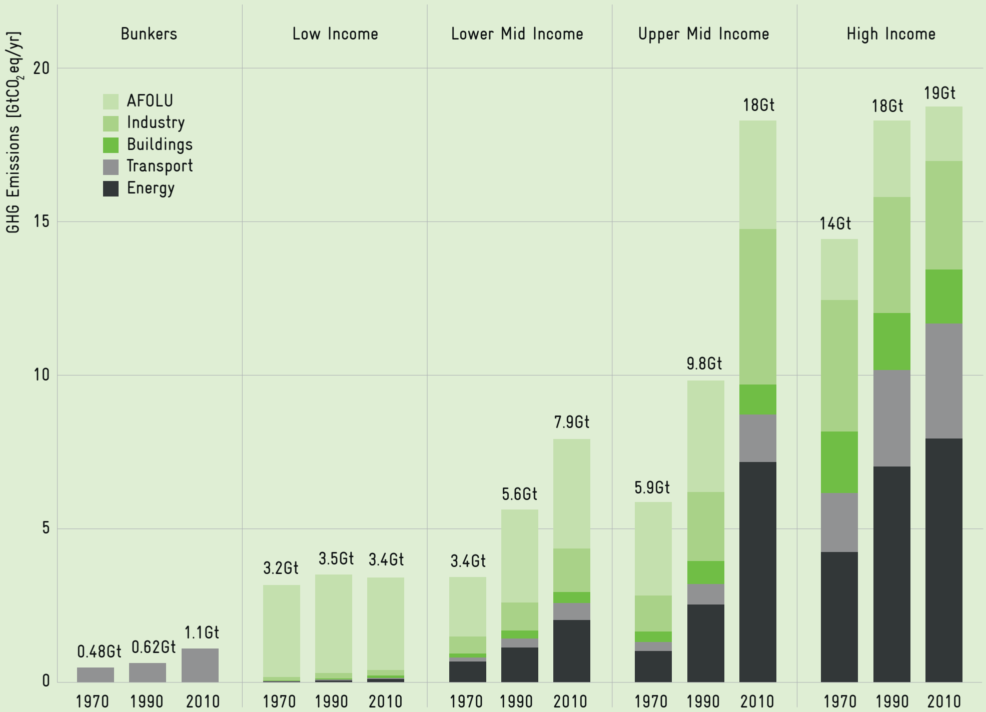
The IPCC divides the AFOLU sector into the following categories for the purposes of emissions accounting:

A(FOLU) – Emissions from agriculture i.e. enteric fermentation 40% (digestion process of ruminants e.g. cattle, sheep, goats etc.), manure left on pasture 16%, emissions from synthetic fertilizers 12%, rice cultivation 10%, manure management 7%, burning of savannas 5%,

(A)FOLU – Emissions from forestry and land use change i.e. primarily due to deforestation and transformation of forests and savannahs into pasture and cropland. It includes removals (sequestration) due to reforestation/regrowth; and emissions from degradation of organic soils e.g. peatland through drainage and burning of woodlands and crop residues.

The figure below summarizes the emissions from 1970 to 2009 in the total AFOLU sector indicating the dominating GHGs N_2O, CH_4 and CO_2 for each of the categories. Note that emissions are generally expressed in

Figure 2 **Trends of global emissions per country income group and per sector**



Source: adapted from Smith et al. 2014, 'Bunkers' refer to emissions from international transportation and thus are not, under current accounting systems, allocated to any particular nation's territory.

CO_2-equivalents (CO_2e), whereby the greenhouse gas effect of CH_4 and N_2O – the global warming potential (GWP) over 100 years – is converted into CO_2e. One unit of CH_4 equals 21 units of CO_2e and one unit of N_2O equals 310 units of CO_2e[2].

The AFOLU sector is responsible for 24% (~10–12 $GtCO_2e$/yr) of anthropogenic GHG emissions. Largest contributors in decreasing order between 2000 and 2009 were land-use change, enteric fermentation, use of peat lands and manure on pasture. Annual GHG emissions from agricultural production in 2000–2009 were estimated at 5.0–5.8 $GtCO_2e$/yr while annual GHG flux from land use and land-use change activities accounted for approximately 4.3–5.5 $GtCO_2e$/yr.

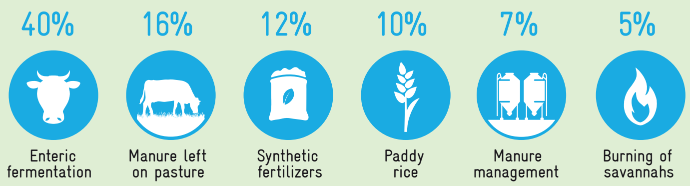
In 2011, 44 % of agriculture-related GHG outputs occurred in Asia, followed by the Americas (25%), Africa (15%), Europe (12%), and Oceania (4%). This regional distribution was constant over the last decade. In 1990 however, Asia's contribution to the global total was smaller i.e. 38% than at present, while Europe's was much larger (21%) (FAO 2015).

Most of agriculture's GHG emissions are concentrated in only a few countries, and result from growing just a few crops. More than half the N_2O emissions from croplands comes from three countries: China (31 %), India (11%), and the U.S. (14%). Similarly, producing just three crops – wheat, maize, and rice – accounts for roughly half of global N_2O emissions from agriculture. Further, nearly two thirds of methane emissions from rice cultivation are from China (29%) and India (24%).

[2] See Global Warming Potentials under the UNFCCC: http://unfccc.int/ghg_data/items/3825.php

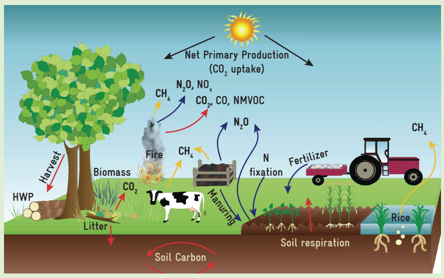
Info box 1 Greenhouse gases and emissions from AFOLU and agriculture

Agriculture alone contributes 10–12 % of global GHG emissions



Figures for the largest emitters in agriculture are averages for the period 2005-2014 (FAO 2016a)

Carbon dioxide (CO_2)	▸ microbial decomposition of soil organic matter (SOM) and dead organic matter ▸ deforestation ▸ burning of organic matter
Methane (CH_4)	▸ enteric fermentation from ruminants (cattle, sheep, goats) ▸ methane production under anaerobic conditions in soils (e.g. during rice cultivation) and manure storage ▸ burning of organic matter
Nitrous oxide (N_2O)	▸ nitrification and denitrification due to application of synthetic and organic fertilizers to soils ▸ burning of organic matter



Sources and sinks in the AFOLU Sector (IPCC 2006)

GHG emissions from the AFOLU sector account for 24 % of the total emissions (IPCC, 2014). The AFOLU sector is the second largest emitter

Source: FAO 2016a, FAO 2015, Smith et al. 2014

Since the IPCC Fourth Assessment Report (AR4) was published in 2007, emissions from the AFOLU sector have remained similar in absolute terms, but the share of AFOLU emissions has decreased to 24% (in 2010), largely due to increases in emissions in the energy sector. Concerning global forestry and other land use emissions, most models indicate a decline over the most recent years (-14%), largely due to decreasing deforestation rates and increased afforestation. Emissions from agriculture A(FOLU) increased during the past 10 years by 8% per annum (Smith et al. 2014) driven by the rapid increase of livestock production and intensive agricultural production.

Table 1 shows that emissions from synthetic fertilizer had the highest increase over the last 50 years.

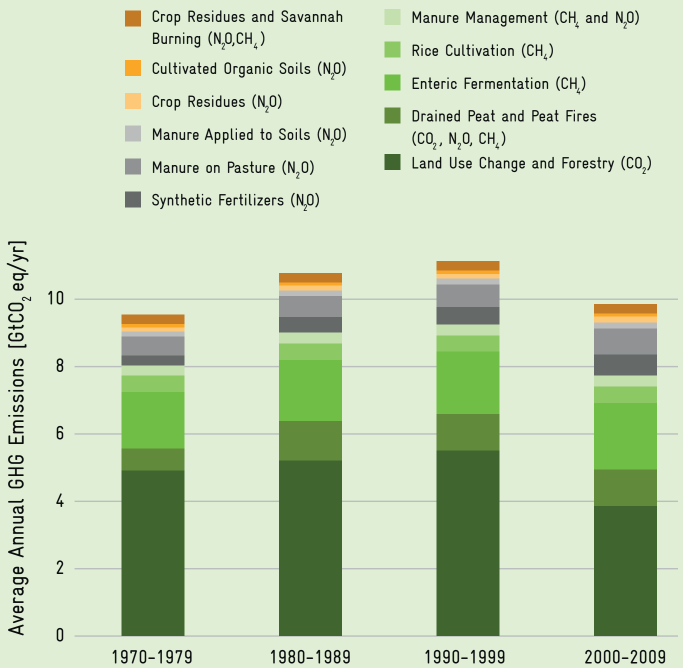
Table 1 Increases in emissions from 1961 to 2010

Emission source	Percent (%)
Synthetic fertilizers	900
Manure (either organic fertilizer on cropland or manure deposited on pasture)	73
Enteric fermentation	50
Paddy rice cultivation	41

Source: Tubiello et al., 2013; FAOSTAT, 2014

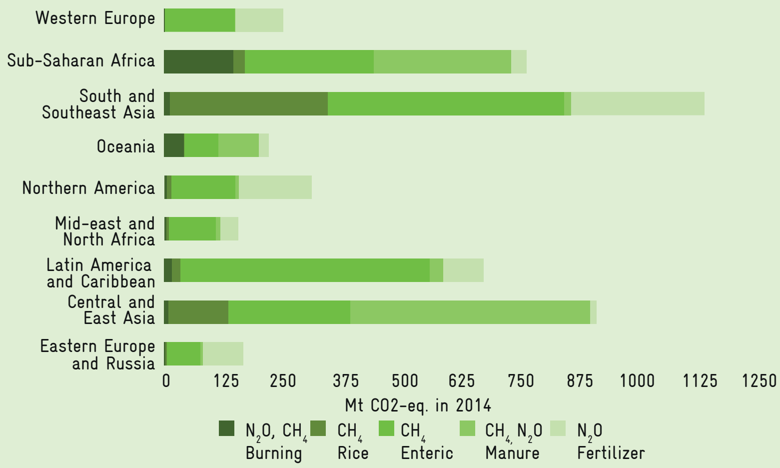
To meet future food demand with more meat consumption in developing countries; increasing crop production through land clearing and intensification; and developed countries increasing production through intensification - it is estimated that global agricultural emissions will increase by at least 30 % by 2050 (Food Matters 2016).

Figure 3 Development of main AFOLU emission categories expressed in CO_2e



Source: Smith et al. 2014

Figure 4 Emissions from agriculture by region and emission source in 2011



Source: Food Matters 2016

2.2 Forestry and other land use

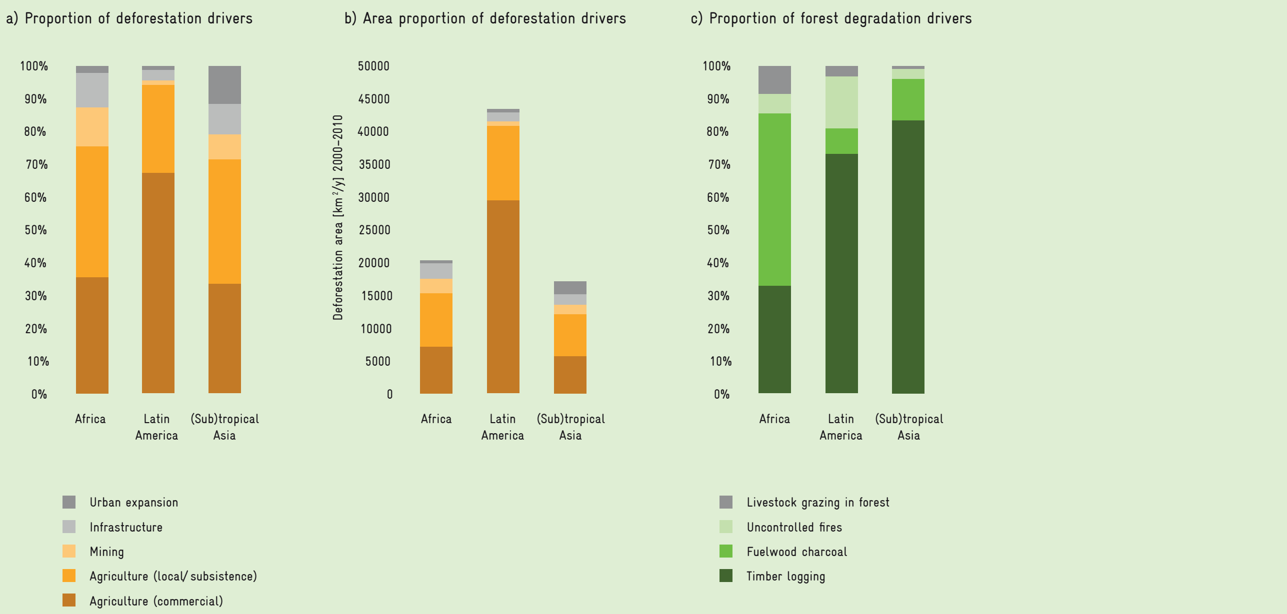
Greenhouse gas emissions and removals in forestry and other land use consist mainly of CO_2 emissions linked to the release (oxidation) and fixation (sequestration) of organic matter following human disturbance. These emissions account for 12% of global greenhouse gas emissions and can be subdivided into emissions from forestland (63%) (deforestation and forest degradation), cropland and grassland (36%), which are dominated by emissions from drainage and fires on organic soils and a relatively small share (1%) of non-CO_2 emissions from burning biomass (forest and peat fires) especially through land clearing for agriculture (FAO 2014).

The main share of forestry and land use emissions is resulting from forest loss and forest degradation in tropical countries. Deforestation is defined as a land-use change from forest to other land uses, whereas forest degradation is defined as a reduction in tree biomass density from human or natural causes, or as a net annual decrease of carbon stock density in forestland.

During the period 2011 – 2015 remaining forests and afforestation have in the average stored 2.1 Gt of CO_2 per year on a global scale. According to FAO estimates, 50% of the estimated sink was due to net growth in planted forests. If contributions from deforestation and forest sinks are combined, then forests represent a net source of emissions with an average of 0.8 Gt of CO_2 per year during the period 2011–2015. FAO data indicate a decrease of more than 25 % in total carbon emissions from forests between 2001 and 2015, due to a slowing in global deforestation rates. Specifically, global emissions from deforestation have declined from 3.9 to 2.9 Gt of CO_2 per year over the period 2001 – 2015 (Tubiello et al. 2014). Emissions from forest degradation have significantly increased during the same period, from 0.4 to 1.0 Gt CO_2 per year (FAO, 2016b).

According to Hosonuma et al. (2012), the reasons for deforestation and forest degradation are considerably different between Africa, Latin America and Asia. Figure 5 shows that for the period of 2000 – 2011 commercial agriculture was the main deforestation driver in Latin America, whereas in Africa subsistence agriculture

Figure 5 Deforestation and forest degradation drivers from 2000-2010



Source: *Kissinger et al. (2012)*

has been a bigger driver than commercial agriculture. The production of fuelwood and charcoal was the main cause for forest degrada-tion in Africa, in Latin America and Asia timber logging dominated.

Until 2012, about half of the tropical deforestation occurred in just two countries. Brazil accounted for 34 per-cent of tropical deforestation, mainly due to producing timber, cattle, and soybeans. Indonesia accounted for 17 % of tropical forest loss, mostly driven by the expansion of oil palm and wood plantations (Food Matters 2016).

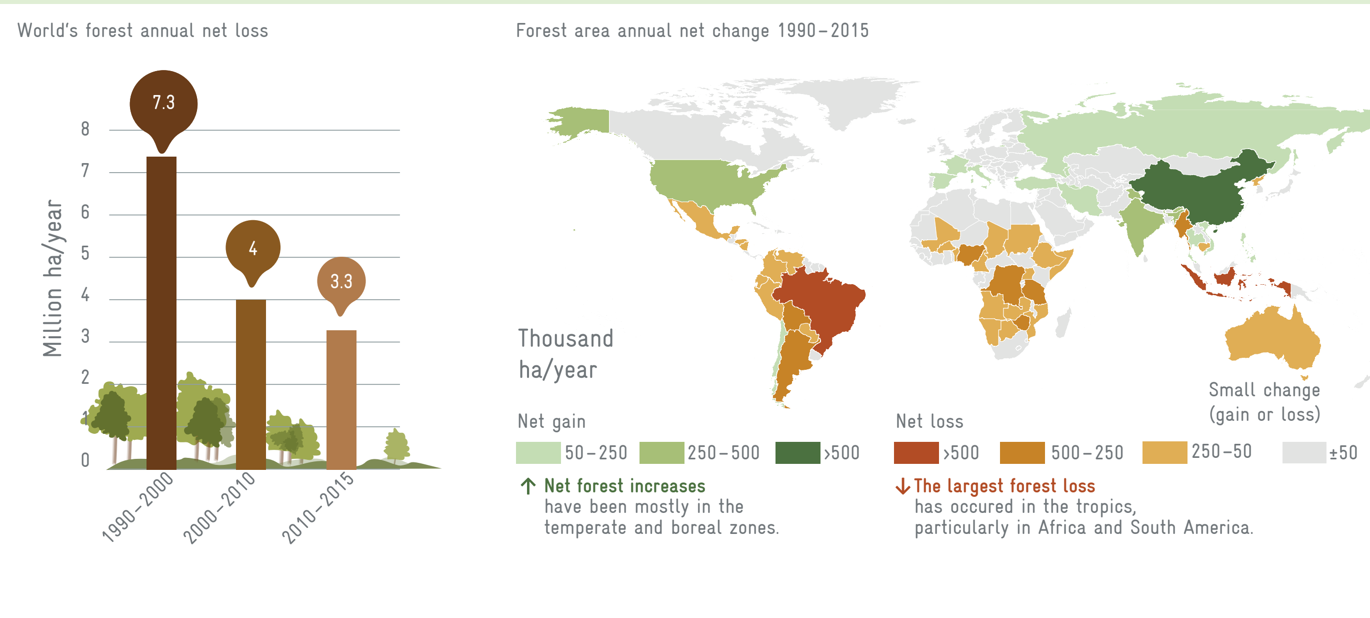
The terrestrial biosphere is a large store of carbon, holding 7,000 – 11,000 GtCO2 among the above ground vegetation and soils, and carbon stored in permafrost soils (Table 2). This is 4-6 times the amount of CO2 held in the atmosphere and 2-5 times that held in economically via-ble fossil fuel reserves (Price et al. 2016).

Table 2 Carbon pools in the environment based on IPCC AR5 in $GtCO_2$

Carbon pool	$GtCO_2e$
Atmosphere	3,040
Fossil fuel reserves	3,700 – 7,100
Vegetation	1,650 – 2,400
Soils	5,500 – 8,800
Permafrost soils	4,000 – 5,500
Ocean	140,000
Marine biota	10
Ocean organic carbon	2,600
Marine sediments	6,400

Source: adapted from Price et al. 2016

Figure 6 Forest area changes based on the Forest Resource Assessment 2015



Source FAO 2016b

According to the latest Forest Resource Assessment (FAO 2015), the world's forests store an estimated 296 Gt of carbon in both above- and below-ground biomass, which contains almost half of the total carbon stored in forests. Soil organic carbon, litter and deadwood form the other half.

Regarding different biomes, Table 3 shows that the carbon stock density is highest in wet-lands followed by boreal forests. Tropical forests and temperate grasslands have the same stock densities whereas tropical savannahs compare to temperate forests. Cropland and (semi-)deserts have the lowest stock densities.

Table 3 **Global carbon stocks in vegetation and top one meter of soil**

Biome	Area (million km²)	Carbon stocks(Pg CO_2-eq)			Carbon stock concentration (Pg CO_2-eq M km²)
		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	2,011	60

Source: Bellarby et al. 2008/IPCC 2001

2.2 Livestock production

Livestock: an important global commodity

Globally, the livestock sector directly supports 600 million smallholders in developing countries and contributes to employment of at least 1.3 billion people (Perry and Sones 2007; Thornton et al. 2006, both cited in Herrero et al. 2009). Livestock is an important provider of food, transport, hides and social safety. It also provides manure for soil fertility management and cooking (Herrero et al. 2009). An expected growth of the world population from 7.2 billion to 9.6 billion in 2050, growing prosperity and urbanization will not only increase the demand for food and other agricultural products, but also shift consumption patterns to more animal sourced-foods. Largest producers in 2014 were the USA, China and Brazil (Figure 7).

Compared to consumption levels in 2000, it is projected that by 2030, demand for pork and eggs will increase by 65 – 70%; for beef, dairy products and mutton by 80 – 100%; and demand for poultry meat may increase by 170% (FAO 2011a). Growth demand for poultry will be particularly strong in South Asia (mainly driven by trends in India), for beef and dairy products in East Asia (mainly accounted for by trends in China) and strong growth for all product types is foreseen across Africa. Overall, the highest growth in total and per-capita consumption of animal-source foods is projected to occur in low and lower middle income countries (FAO 2011a).

Land required for livestock production, including land for cultivation of feed and fodder crops, accounts already for 70% of the global agricultural area (Steinfeld et al. 2006). Furthermore, the livestock sector is a driver of deforestation and forest degradation, primarily due to the conversion of forests to pastures and cropland for feed production (Fearnside 2005, Nepstad et al. 2006, Barona et al. 2010). Intensive livestock production in industrial units is often a cause of water and soil pollution. In addition to direct impacts, livestock products have large water footprints, mainly due to feed production, and have higher nutrient needs per unit of produced energy than plant-based products (Mekkonen and Hoekstra 2012; Bouwman et al. 2011).

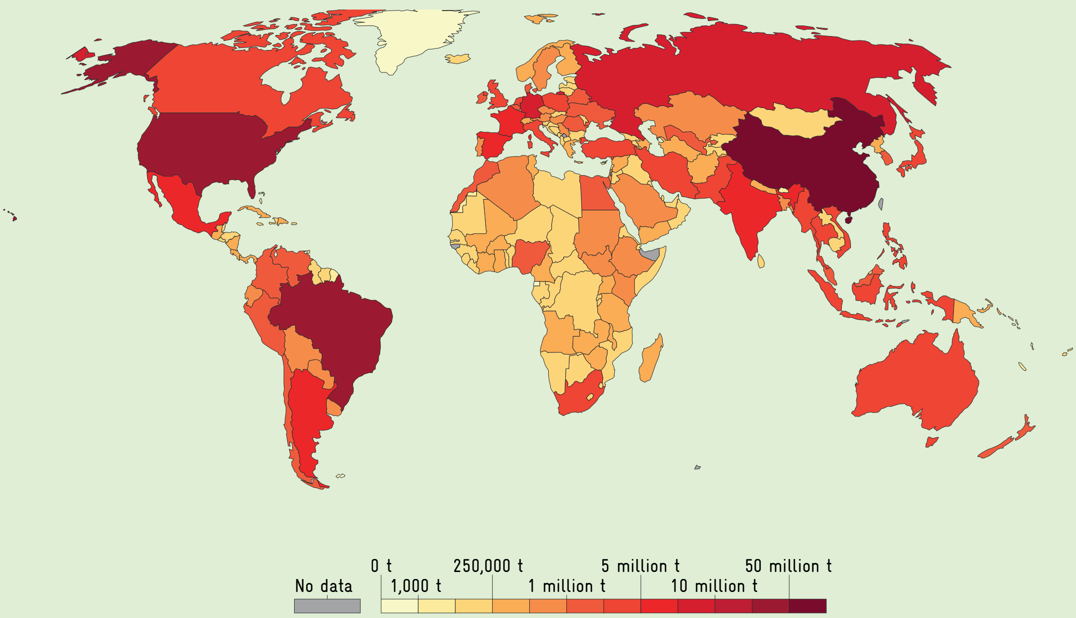
Livestock as contributor to greenhouse gas emissions

Agricultural production contributes 10-12% to global GHG emissions (see Info box 1), more than half of which is from enteric fermentation, manure left on pasture and manure management (FAO 2016a). Global livestock emissions have risen at a rate of more than 1% per annum in the last two decades. GHG emissions of the livestock sector are mainly comprised of methane (44%), nitrous oxide (29%) and carbon dioxide (27%).

Emissions caused by livestock differ between species and thus the emissions of products derived from these species differ accordingly. Of the major global livestock commodities meat, milk and eggs, beef clearly is the largest contributor (65%) to livestock emissions (Table 4). Dairy has a smaller overall contribution to GHG of the livestock sector and milk has smaller specific emissions (per kg) than beef. Dairy cattle are dual purpose animals that produce milk and meat. Emissions caused by dairy cattle can thus both be allocated to milk and beef production (Gerber et al. 2013a).

Figure 7 **Global meat production in tonnes in 2014**

Total meat production, measured in tonnes. Meat includes cattle, poultry, sheep/mutton, goat, pigmeat, and wild game. Figures are given in terms of dressed carcass weight, excluding offal and slaughter fats.



Source: UN Food and Agricultural Organization (FAO)

Source: Ritchie et al. (2017)

Small ruminants account for 6.5% of livestock sector emissions. Similarly as for cattle, the main sources of emissions include enteric fermentation and feed production. Emissions cannot only be accounted to meat and milk production, but also to important 'by-products' such as wool or cashmere.

With only 9% of the total livestock sector emissions, pork production is a relatively small contributor to livestock emissions. The main emission sources of pork production are feed production, contributing to 48% of pork production emissions, and manure storage and processing. Carbon dioxide is thus the major source of pork production emissions, followed by methane (Gerber et al. 2013a).

Finally, the poultry sector contributes 8% of global livestock sector emissions; of which chicken meat accounts for roughly 5%. As within the pork sector, the largest contributor to the sub-sector's emissions is feed production (57%). Energy used on-farm, for feed production and post-farm contributes 35 – 40% of the poultry sector's emissions (Gerber et al. 2013a).

Table 4 Global and specific greenhouse gas emissions from major livestock species and commodities[3]

Animal species and commodities	% of total livestock sector emissions	Specific GHG emissions (CO_2-eq per kg)
Cattle	65[4]	
Beef[5]	41	46.2
Milk[6]	20	2.8
Small ruminants	6.5	
Meat	4.1	23.8
Milk	1.8	6.5
Other goods and services (e.g. fibres)	0.6	
Pig (pork)	9	6.1
Poultry	8	
Meat	5.1	5.4
Eggs	2.9	3.7

Source: adapted from Gerber et al. (2013a)

Large differences in specific greenhouse gas emissions exist between regions (Figure 8). Emissions per kg of beef for example are high in extensive grazing systems like in Latin America (LAC), South Asia and Sub-Saharan Africa (SSA). They are much lower in intensive systems like in North America and Europe. Depending on the production system, even within countries a large variety in emission intensity can exist.

Variation across regions are due to differences in livestock production systems and animal husbandry practices, varying from extensive, pasture-based, to intensive and industrialized production systems. Higher specific emissions per unit in beef production are mainly caused by poor feed quality and digestibility, leading to higher methane emissions by enteric fermentation. Furthermore, lower slaughter weights and higher age at slaughter lead to more emissions per kilogram beef produced, and overall more emissions due to a longer life span.

[3] Other livestock emissions not included in this table include emissions from buffalo.

[4] Total emissions from cattle include emissions from beef and milk production, as well as other goods and services such as animal draught power or manure used for fuel.

[5] Emission intensity for beef is expressed in CO2-equivalents per kilogram carcass weight.

[6] To account for heterogeneity in milk composition, milk is normalized in fat and protein corrected milk (FPCM).

As with beef production, emission intensity in milk production is lowest in high intensity production systems, primarily due to optimal rations reducing methane and manure emissions (Figure 9). Especially in developing countries with low productivity, enteric fermentation is the main source of emissions. Higher milk yields per cow implies that the cow spends relatively less energy on maintenance and reproduction purposes, hence an efficiency gain is realized. In intensive systems, emissions are mainly caused by feed production and processing and manure management (Gerber et al. 2013a).[7]

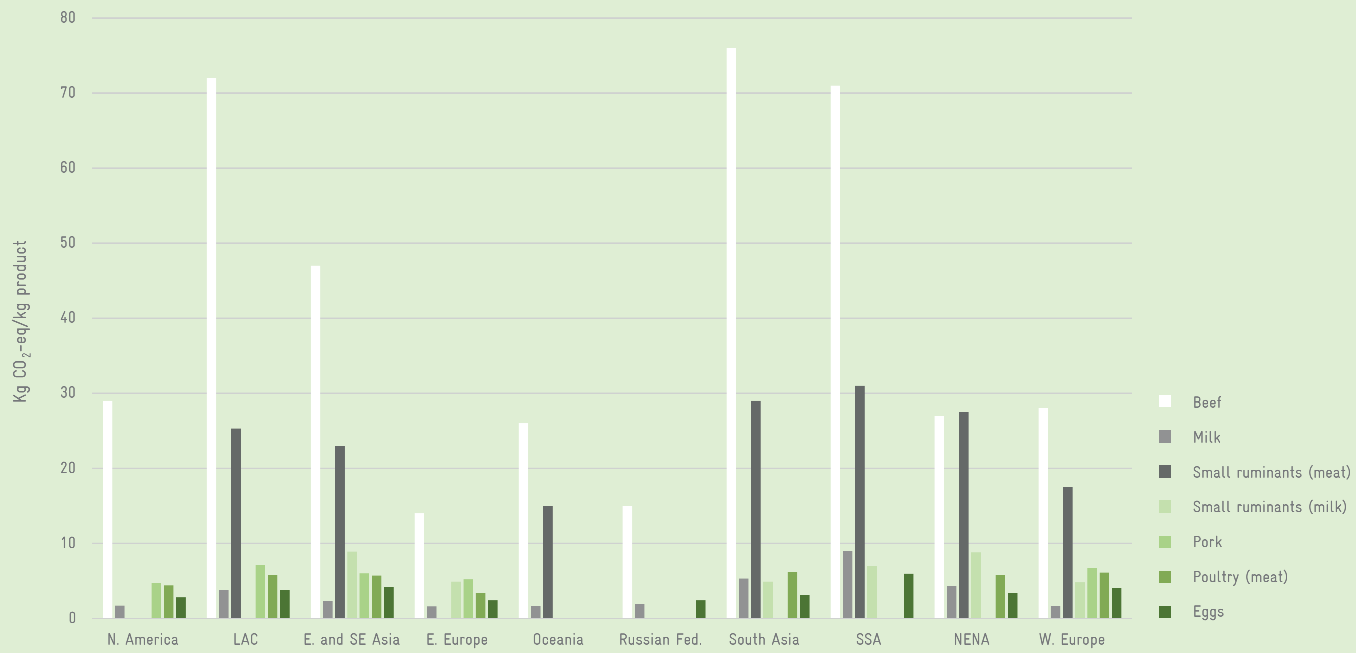
Small ruminant products (meat, milk, wool) are mainly produced in East and South East Asia, Near East and North Africa and Sub-Saharan Africa. Sheep and goat milk and lamb and mutton meat are also produced in Western Europe and Oceania. The emission intensity is highest in East and South East Asia and Near East and North Africa due to extensive pasture-based production systems.

In pork production, industrialized systems account for most pork production globally and thus total emissions. Emission intensity is highest in systems with intermediate intensity e.g. characterised by a higher share of rice products in fodder rations with poor feed conversion[8]. Although small-scale 'backyard' production systems with low quality feed result in relatively high manure emissions, these are offset by low emissions from feed

[7] All regions with less than 1% of global pork production and less than 2% global poultry (meat) and egg production are excluded.

[8] The conversion of feed into livestock products is referred to as the feed conversion factor, and globally used as an indicator of livestock production efficiency.

Figure 8 **Regional variation in emission intensity for each key livestock product**



Source: adapted from Gerber et al. (2013a) production. Hence, in contrary to milk production, emission intensity of pork production is lowest in backyard systems.

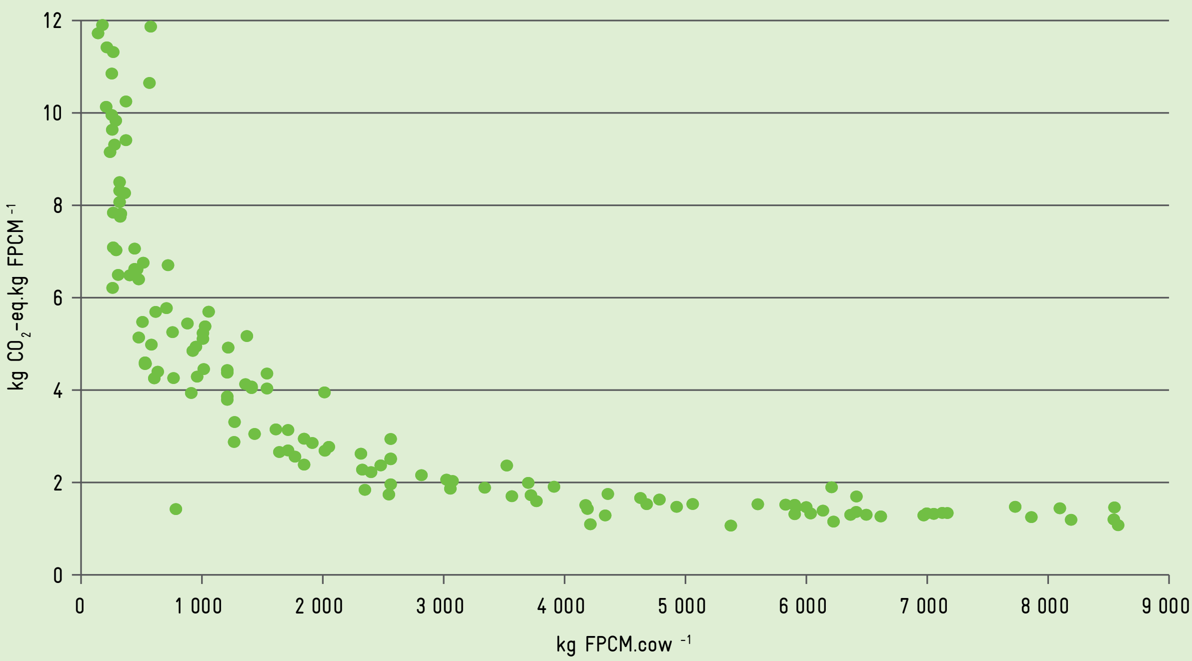
Emission intensity of poultry meat and egg production is lowest in intensive production systems. Intensively managed broilers and laying hens are able to quickly and efficiently convert low-emission/high quality feedstuffs into meat and eggs. Chickens in backyard systems however are usually slow-growing, spend more energy scavenging for feed, depend on low quality feedstuffs and have a higher proportion of unproductive animals in the herd (Gerber et al. 2013a).

2.3 Emissions from fertilizer application

Fertilizer: an essential input to agricultural production

Synthetic nitrogen fertilization has substantially contributed to increase global food production and ensure food security (Figure 10). However, applied in excess and during inappropriate periods, synthetic fertilizer releases considerable amounts of particularly harmful nitrous oxide. N_2O is harmful even in small quantities due to its high global warming potential (298 times more than CO_2) and its long persistence in the atmosphere of about 120 years. In addition to the release of nitrous oxides after application, the energy-intensive production is generating emissions, which are accounted for in the industrial sector. Organic fertilizers (manure) also emit nitrous oxides and methane if not stored, managed and applied appropriately.

Figure 9 Relationship between GHG per kg of milk and annual milk output per cow (Fat and Protein corrected milk (FPCM) output)



Source: Smith et al. 2014

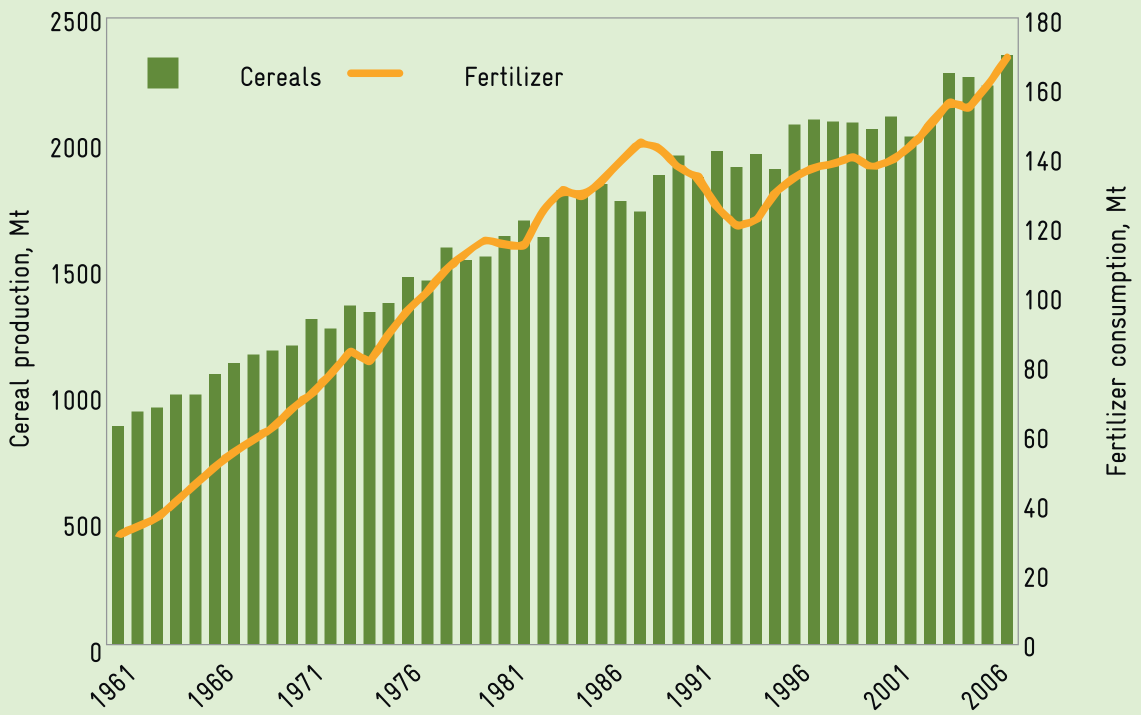
With increasing fertilizer application rates, the nitrogen use efficiency is decreasing (Lassaletta et al. 2014). Currently, the global average nitrogen use efficiency is only about 50% (Bodirsky et al. 2012), meaning that half of the input is not used and released into surface or ground water or into the atmosphere.

Nitrogen fertilizer use varies largely among regions (Figure 11). In Western Europe, nitrogen fertilizer use has decreased since 1995 due to environmental legislation (Nitrate Directive in 1991). In the USA it has arrived at a steady level, whereas in East and South Asia it is still increasing. 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, India, USA, EU-28 and Brazil are the world's top five fertilizer consumers, together accounting for 94% of global fertilizer consumption. In China, nitrogen and fertilizer subsidy policies contributed much to the sharp increase in synthetic fertilizer application. Half of the world's synthetic nitrogen is used for cereals (IFA 2017).

Africa only uses 2% of nitrogen fertilizers produced, whereas Latin America and the Caribbean (LAC) remains at a slightly higher level. Here the nitrogen supply to soils is, on average, insufficient to maintain soil fertility, resulting in nutrient depletion and loss of soil organic matter (soil mining) in scarcely or unfertilized soils (Bellarby et al. 2008).

Figure 10 **Fertilizers have contributed largely to increased global food production during the past 50 years**



Source: IFA Statistics, 2007 and FAOSTAT, 2008, in Roberts, 2009)

Fertilizer as contributor to GHG emissions

Organic fertilizer

Manure application on pasture and manure management are contributing, 16 % and 7 %, respectively, of the livestock emissions (see Info box 1).

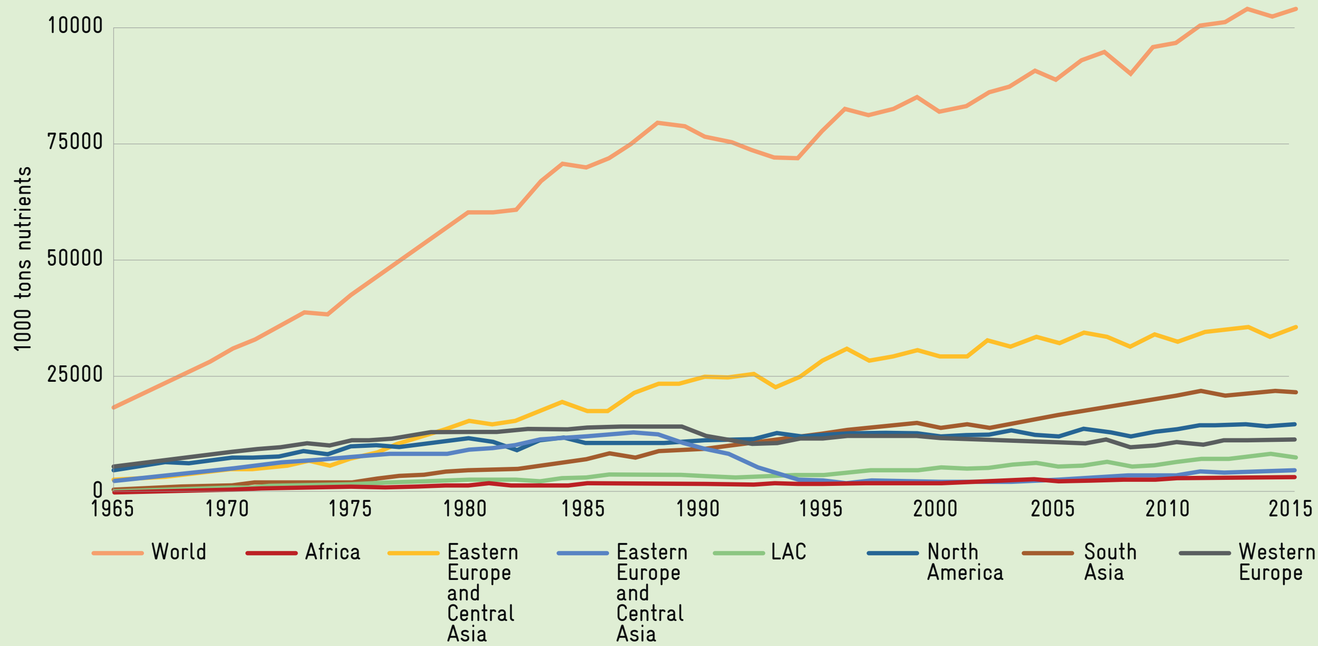
Manure is either directly left on pasture to decompose or is collected on farm in kraals, livestock gutters and stables. Slurry and farmyard manure of poultry, pork, cattle and small ruminants are produced in feedlots. These farm manures are recycled back as fertilizer to pastures and cropland. Global emissions from both types of manure application grew by roughly one % per year during the past decades. The category manure left on pasture produces far larger emissions (725 Mt CO_2e/yr) than manure applied to cropland (110 Mt CO_2e/yr) (FAOSTAT 2013).

Two-thirds of manure left on pasture come from grazing cattle, with smaller contributions from swine, sheep and goats.

Synthetic nitrogen fertilizers

Emissions from synthetic fertilizer application grew much faster than from manure, at a mean annual growth rate of 3.5% from 2001 to 2011, down from a much faster growth in earlier decades (Tubiello et al. 2014).

Figure 11 Nitrogen fertilizer consumption in different world regions



Source: IFADATA 2017

Considering current trends, synthetic fertilizers will become a larger source of emissions than manure deposited on pasture in less than 10 years.

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 under climate change aspects.

In addition to the nitrous oxide emissions from the application of synthetic nitrogen fertilizers, the production of the fertilizer also contributes to the release of CO_2 from energy use. These emissions are estimated at 1.2% of the total world GHG emissions (Bellarby et al. 2008, Wood and Cowie 2004) and are accounted for in the industry sector.

2.4 Rice production

Rice – the world's most important staple food crop

Rice is the staple food of more than half of the world's population – roughly 3.5 billion people depend on rice for more than 20% of their daily calories. Human consumption in 2009 accounted for 78% of total rice production, compared with 64% for wheat and 14% for maize. Of these three major crops, rice is by far the most important food crop for people in low- and lower-middle-income countries.

Asia accounts for 90% of global rice consumption, and total rice demand there continues to rise. Outside Asia, per capita consumption continues to grow. Rice is the fastest growing food staple in Africa, and one of the fastest in Latin America (CGIAR 2017).

Paddy rice cultivation as contributor of GHG emissions

Methane emissions are caused by irrigated rice. With 10% of the global agricultural emissions, irrigated rice is the fourth important source of agricultural emissions after enteric fermentation, manure left on pasture and synthetic fertilizer.

On flooded rice fields, methane is produced under anaerobic conditions and released into the atmosphere via gas spaces (aerenchym) in the rice roots and stems. A smaller portion of methane bubbles up from the soil and/or diffuses slowly through the soil and overlying flood water (FAO 2017).

Emissions from irrigated rice are mainly produced in Asia (90%), where most irrigated rice is produced. From 1961 to 2010, global emissions increased with an average annual growth rate of 0.4%/yr.

In addition, the release of methane depends on soil characteristics, crop management and fertilizing practices, (Gattinger et al. 2011). Nitrogen fertilizing causes, in addition, considerable nitrous oxide emissions.

Expected expansion of rice grown under continuous flooding determines the future increase of methane emissions from rice. The maximum estimated area increase is projected at 16% 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, sprinkler- or drip-irrigation) or adoption of new cultivars that emit less methane might contribute to reduce methane release in existing flooded rice production areas.

2.5 Production and utilization of bioenergy

Biofuels are a renewable source of energy that have the potential to substitute fossil fuels. However, depending on the feedstock and the conversion process they also generate emissions and may not significantly reduce emissions compared to fossil fuels. Furthermore, biofuels can compete with food production for scarce water and fertile land resources.

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 improved energy cycle management and efficiency. Table 5 gives an overview of potentials and challenges related to bioenergy production.

Table 5 IPCC summary on potential positive/negative bioenergy impacts based on scientific findings

Institutional		Scale
May contribute to energy independence (+), especially at the local level (reduce dependency on fossil fuels) (2, 20, 32, 39,50)	+	Local to national
Can improve (+) or decrease (–) land tenure and use rights for local stakeholders (2, 17, 38, 50)	+/–	Local
Cross-sectoral coordination (+) or conflicts (–) between forestry, agriculture, energy, and / or mining (2, 13, 26, 31, 60)	+/–	Local to national
Impacts on labor rights among the value chain (2, 6, 17)	+/–	Local to national
Promoting of participative mechanisms for small-scale producers (14, 15)	+	Local to national
Social		**Scale**
Competition with food security including food availability (through reduced food production at the local level), food access (due to price volatility), usage (as food crops can be diverted towards biofuel production), and consequently to food stability. Bio-energy derived from residues, wastes, or by-products is an exception (1,2, 7, 9, 12, 18, 23)	–	Local to global
Integrated systems (including agroforestry) can improve food production at the local level creating a positive impact towards food security (51, 52, 53, 69, 73, 74). Further, biomass production combined with improved agricultural management can avoid such competition and bring investment in agricultural production systems with overall improvements of management as a result (as observed in Brazil) (60, 63 66, 67, 70, 71)	+	Local
Increasing (+) or decreasing (–) existing conflicts or social tension (9, 14, 19, 26)	+/–	Local to national
Impacts on traditional practices: using local knowledge in production and treatment of bioenergy crops (+) or discouraging local knowledge and practices (–) (2, 50)	+/–	Local
Displacement of small-scale farmers (14, 15, 19). Bioenergy alternatives can also empower local farmers by creating local income opportunities	+/–	Local
Promote capacity building and new skills (3, 15, 50)	+	Local
Gender impacts (2, 4, 14, 15, 27)	+/–	Local to national
Efficient biomass techniques for cooking (g., biomass cookstoves) can have positive impacts on health, especially for women and children in developing countries (42, 43, 44)	+	Local to national
Environmental		**Scale**
Biofuel plantations can promote deforestation and/or forest degradation, under weak or no regulation (1, 8, 22)	–	Local to global
When used on degraded lands, perennial crops offer large-scale potential to improve soil carbon and structure, abate erosion and salinity problems. Agroforestry schemes can have multiple benefits including increased overall biomass production, increase biodiversity and higher resilience to climate changes. (59, 64, 65, 69, 73)	+	Local to global
Some large-scale bio-energy crops can have negative impacts on soil quality, water pollution, and biodiversity. Similarly potential adverse side-effects can be a consequence of increments in use of fertilizers for increasing productivity (7, 12, 26, 30). Experience with sugarcane plantations has shown that they can maintain soil structure (56) and application of pesticides can be substituted by the use of natural predators and parasitoids (57, 71)	–/+	Local to transboundary
Can displace activities or other land uses (8, 26)	–	Local to global
Smart modernization and intensification can lead to lower environmental impacts and more efficient land use (75, 76)	+	Local to transboundary
Creating bio-energy plantations on degraded land can have positive impacts on soil and biodiversity (12)	+	Local to transboundary
There can be tradeoffs between different land uses, reducing land availability for local stakeholders (45, 46, 47,48, 49). Multicropping system provide bioenergy while better maintaining ecological diversity and reducing land-use competition (58)	–/+	Local to national
Ethanol utilization leads to the phaseout of lead addititives and methyl tertiary-butyl ether (MBTE) and reduces sulfur, particulate matter, and carbon monoxide emissions (55)	+	Local to global
Economic		**Scale**
Increase in economic activity, income generation, and income diversification (1, 2, 3, 12, 20, 21, 27, 54)	+	Local
Increase (+) or decrease (–) market opportunities (16, 27, 31)	+/–	Local to national
Contribute to the changes in prices of feedstock (2, 3, 5, 21)	+/–	Local to global
May promote concentration of income and/or increase poverty if sustainability criteria and strong governance is not in place (2, 16, 26)	–	Local to regional
Using waste and residues may create socio-economic benefits with little environmental risks (2, 41, 36)	+	Local to regional
Uncertainty about mid- and long-term revenues (6, 30)	–	National
Employment creation (3, 14, 15)	+	Local to regional
Technological		**Scale**
Can promote technology development and/or facilitate technology transfer (2, 27, 31)	+	Local to global
Increasing infrastructure coverage (+). However if access to infrastructure and/or technology is reduced to few social groups it can increase marginalization (–) (27, 28, 29)	+/–	Local
Bioenergy options for generating local power or to use residues may increase labor demand, creating new job opportunities. Participatory technology development also increases acceptance and appropriation (6, 8, 10, 37, 40)	+	Local
Technology might reduce labor demand (–). High dependent of tech. transfer and/ or acceptance	–	Local

Source: Smith et al. 2014

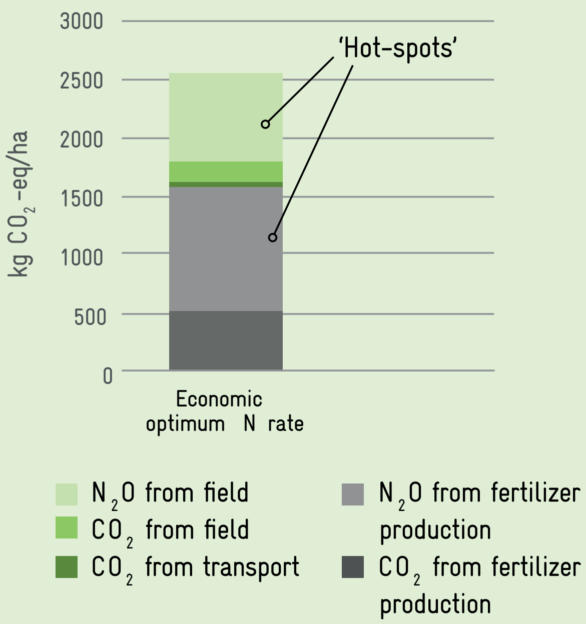
2.6 Agricultural value chains

Regional and global agricultural value chains are often highly complex systems. GHG emissions arise at multiple stages along these chains. According to the IPCC accounting logic, the production stage of agriculture is the only stage represented as an aggregate. It is the most emissions intensive step in the value chain. Emissions both up- and downstream of the on-farm production are relatively minor in production systems like livestock and rice, because the high emissions intensity of the production stage outweighs emissions created before and after. In other systems like cocoa and coffee, production stage emissions often outweigh up- and downstream emissions because a) deforestation adds to the emissions burden and b) systems are often low-input, contributing very few emissions from the manufacturing of inputs.

Emissions in the logistics chain between farms and end consumers are accounted for in other sectors such as industry, transport and manufacturing under IPCC, but are in general small compared to on-farm emissions. Only on-farm emissions from fossil fuel burning, heat and electricity generation are singled out. They contribute 0.87 % of global emissions (Figure 1). This does not consider emissions created during the process of manufacturing farm inputs. No systemic analysis exists as to how much agricultural value chains as a whole contribute to emissions within the industry, transport and manufacturing categories. For certain commodities, life cycle analyses have been carried out, mainly in industrialized countries. The results of such analyses are very case specific and the numbers cannot be extrapolated to regional or global scales. [9]

[9] Economic optimum N rate is the amount of fertilizer needed to achieve maximum yield. Tested for ammonium nitrate on winter wheat by Brentrup et al. 2004.

Figure 12 Carbon footprint of wheat production in the EU, by GHG and sources



Source: Brentrup & Pallière 2008[9]

Upstream emissions

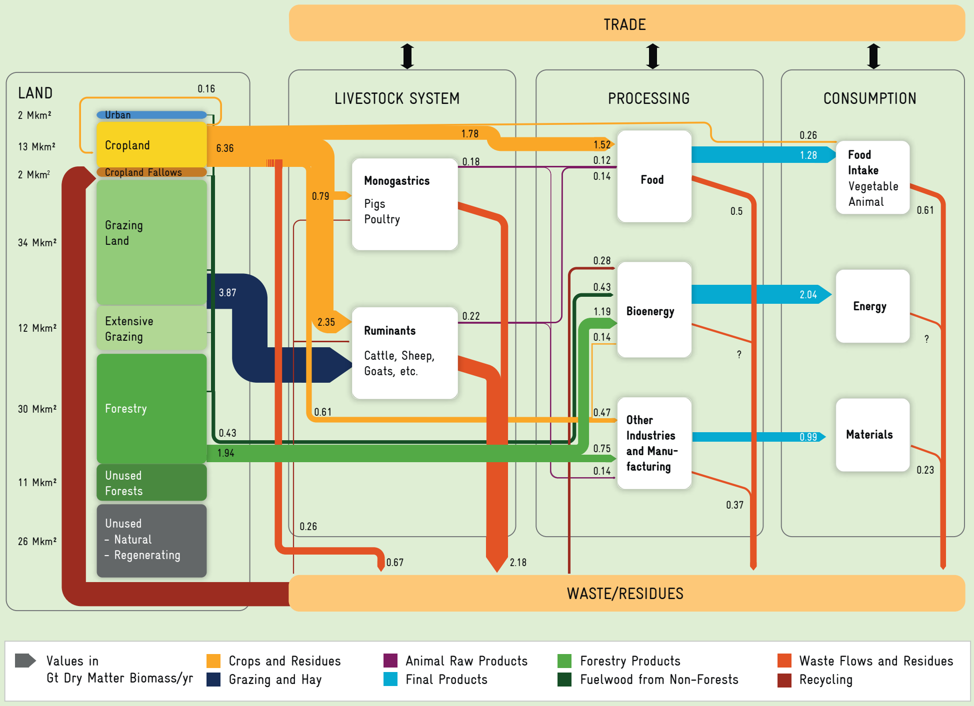
There is no reliable estimate on the percentage of upstream emissions within agriculture, because the IPCC accounting logic draws sectoral lines. Typical emissions intensities for various activities on an industrialized farm are shown below based on data from 2003 (Table 6). The wide range further varies across global regions and can only be seen as indicative. Previous reports have tried to extrapolate these ranges to the global level by multiplying per ha emissions with total arable land area. Due to the high uncertainties involved, such calculations are not very meaningful.

Table 6 GHG intensities of farm operations and production of inputs resulting from fuel and energy use

Practice	Value range	Unit
Tillage	440 – 7,360	kg CO2e/ha
Application of agrochemicals	180 – 3,700	kg CO2e/ha
Drilling or seeding	810 – 1,430	kg CO2e/ha
Combine harvesting	2,210 – 4,210	kg CO2e/ha
Irrigation	3,440 – 44,400	kg CO2e/ha
Pesticide production	220 – 9,220	kg CO2e/ha
Nitrogen fertilizer production	3.294 – 6.588	kg CO2e/kg produced
Phosphorus fertilizer production	0.366 – 1.098	kg CO2e/kg produced

Source: Bellarby et al. 2008 based on Lal 2004

Figure 13 Global biomass flows in 2000, in giga tons dry matter biomass per year



Source: Smith et al. 2014

According to the Millennium Ecosystem Assessment (2005), 18 % of the world's croplands receive supplementary irrigation. The irrigation related emissions are slightly lower compared to the emission reductions related to the productivity increase, measured in GHG per production unit.

The production of nitrogen fertilizer (in the IPCC logic assigned to 'Industry') is very energy intensive. GHG emissions from N fertilizer production are mainly from two sources: Fossil fuel related CO_2 emissions from the ammonia synthesis and N_2O emitted from nitric acid production. A study estimated 410 million tons of CO_2e in 2008, which was equivalent to 0.8 % of global GHG emissions (Bellarby et al. 2008). This figure does not correspond to IPCC numbers, because it follows a different sectoral emission attribution logic. To take the example of industrial wheat production in Europe, fertilizer production can contribute a high percentage of total emissions of a given commodity (Figure 12).

A study in Colombian cocoa production found that 86% of GHG emissions arise at the production stage on farm, and only 12% upstream (Ortiz et al. 2016). Such studies are rare and almost impossible to compare since they set calculation boundaries differently and input intensities between geographies and commodities vary greatly.

Downstream emissions

Figure 13 illustrates the global biomass flows in the agriculture and forestry value chains from the farm gate to the end consumer. The volume of the biomass flows is indicative of the associated GHG emissions since the unit (gigatons dry matter biomass per year) contains carbon as well as the indirect associated emissions and other environmental footprint generated during production as described in above chapters.

The fuel used for the transport and processing of agricultural produce and the refrigerating of perishable foodstuffs is fully accounted for in the transport sector.

At the processing stage, livestock products take a lead in GHG intensity because they require refrigeration, especially in the dairy sector. Transport of meat products generally covers long distances and requires refrigeration as well (FAO 2009a).

Most GHG emissions along the agricultural value chain after production arise from food losses and waste. FAO estimates that the total carbon footprint of food wastage is around 4.4 $GtCO_2$e per year, or about 8% of total global GHG emissions (FAO 2017b). Volumes differ greatly by sub-sector and region. For example, value chain losses account for 5-50% in the East African dairy sector, whereas 20–30% of total maize production is lost somewhere after the farm gate in Central America (Nash et al. 2017). Food loss refers to a decrease in quantity or quality of food during production and distribution. Food waste refers to the removal of food which is fit for consumption, or which has spoiled or expired caused by behaviour, poor stock management or neglect.

The underlying GHG logic is that food losses and waste represent a waste of resources used in production such as land, water, energy and inputs, increasing the GHG emissions in vain (FAO 2011b). In other words, more end consumers could be served with less agricultural production and resources if waste and losses were reduced. One-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. Per capita losses are highest in North America and Europe due to consumer end losses (Figure 14). Production end losses are similar in magnitude across world regions.

Food loss and waste typically occur at various stages of the food supply chain:

- post-harvest losses due to pests and diseases, during harvest, transport and storage;
- losses during processing;

- food waste at trade and retail stages due to products not conforming to commercial standards, e.g. trade classifications for size and weight;
- waste of easily perishable foodstuffs not sold or consumed in time and discarded by retail and consumers.

Current global food loss and waste aggregates to USD 1 trillion in economic costs, around USD 700 billion in environmental costs and around USD 900 billion in social costs (FAO 2015).

Consumption patterns

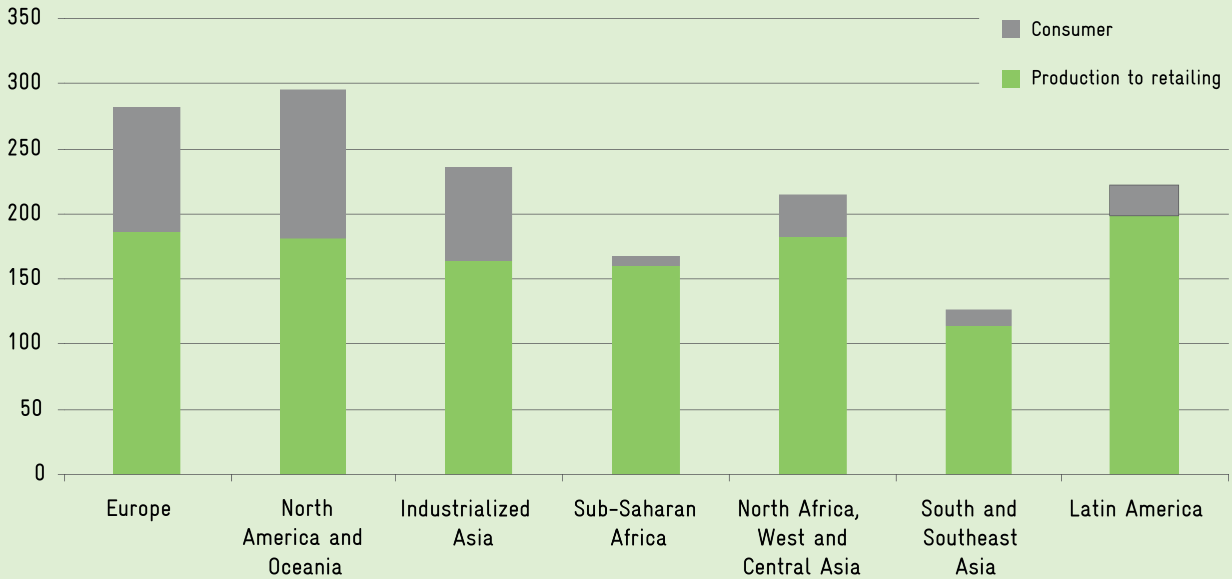
Emission intensities differ greatly by diet type. It is important to mention that these GHG emissions are not additional, but rather a summary of the previous subchapters. The largest share of emissions within a food product's life cycle occurs during primary production. Nevertheless, it is important to understand that different consumption patterns have different GHG footprints, in order to identify demand side measures that can alter consumer behavior and ultimately have a trickle-down effect to the production end of the agricultural value chain.

Animal based proteins are by far the most GHG intensive products (Figure 15). Feed conversion efficiency of livestock types varies considerably. As a result, emission intensity varies among species and products. Per unit of protein provided, beef, goat and sheep meat are much more GHG-intensive than other sources of animal protein such as pork, poultry, milk, fish or eggs. Cereals and oils are the least carbon intensive. Therefore, carbon footprints of diets get smaller if less beef and other ruminant meat is consumed.

There is also a great variation in emission intensities within food groups. Within food categories, e.g. meat, fruit, cereals, etc. locally sourced foods obviously have lower emissions from transport than foods sourced from distant markets. Processing stages also add to emissions. A greenhouse tomato can have emissions five times higher than one grown in season for example.

A wealth of publications (FAO 2011b, Heinrich Böll Foundation 2014, Vermeulen et al. 2012) point to the fact that emissions from the global agri-food system are largely influenced by consumer preference and prevailing diets.

Figure 14 **Per capita food losses and waste, at consumption and pre-consumption stages, in different regions**



Source: FAO 2011b

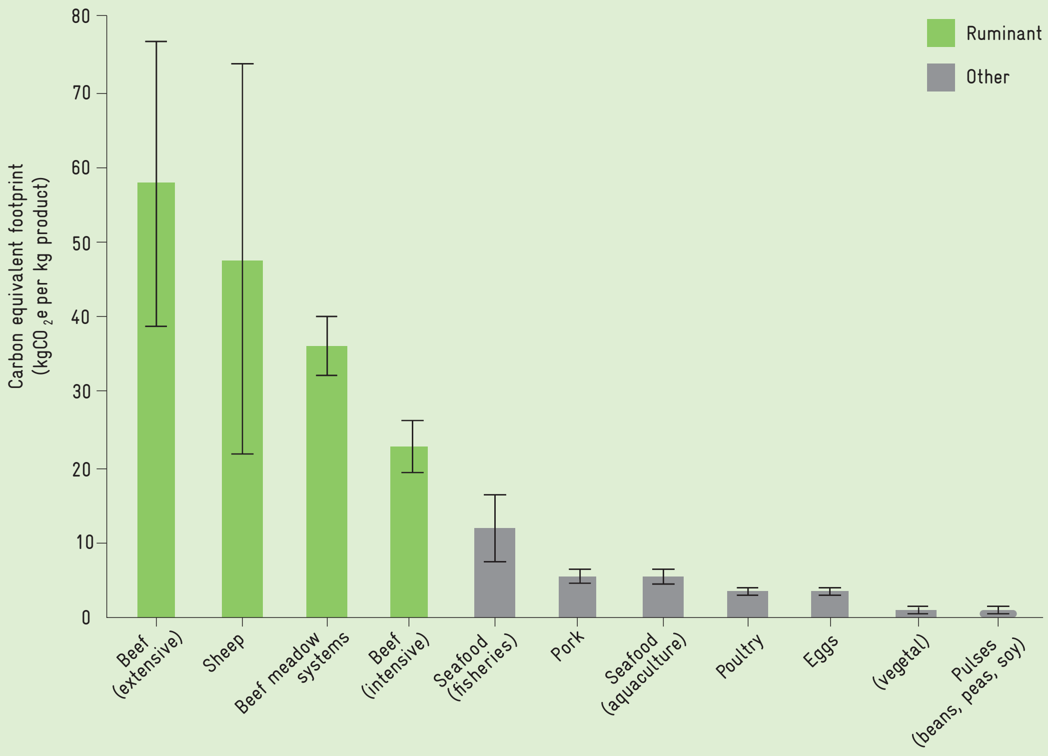
According to the latest flagship reports on global nutrition and food security (HLPE 2017, IFPRI 2017, Global Panel on Agriculture and Food Systems for Nutrition 2016) more meat will be consumed in the transforming economies and by the middle classes around the world in urban areas. Generally, urban dwellers eat more meat than rural populations (Heinrich Böll Foundation 2014). The trends in meat consumption until 2050 predict stagnating consumption in developed countries with 0.4 % annual growth rate. High increases are predicted for South Asia (4.2 %/yr), Sub-Sahara Africa (3.0 %/yr) and the Near East (2.3%/yr) (Table 7).

Table 7 **Trends in global meat consumption**

Regional distribution	Consumption	Growth rate (% per year)	
	2005/2007 '000 tonnes	1981–2007	2005/2007–2050
World	256,179	2.6	1.3
Sub-Saharan Africa	7,33	2.7	3.0
Near East/North Africa	10,292	3.1	2.3
LAC	34,55	3.9	1.3
excl. Brazil	19,955	3.1	1.6
South Asia	6,685	2.1	4.2
East Asia	86,806	6.4	1.4
excl. China	18,967	4.6	2.0
Developed countries	109,382	0.7	0.4

Modified after Alexandratos et al. 2012

Figure 15 **Average carbon footprint of protein-rich solid foods per kilogram of product including error bars**



Source: Ripple et al. 2014


3
Mitigation of GHGs in agriculture and land use change

3.1 General considerations

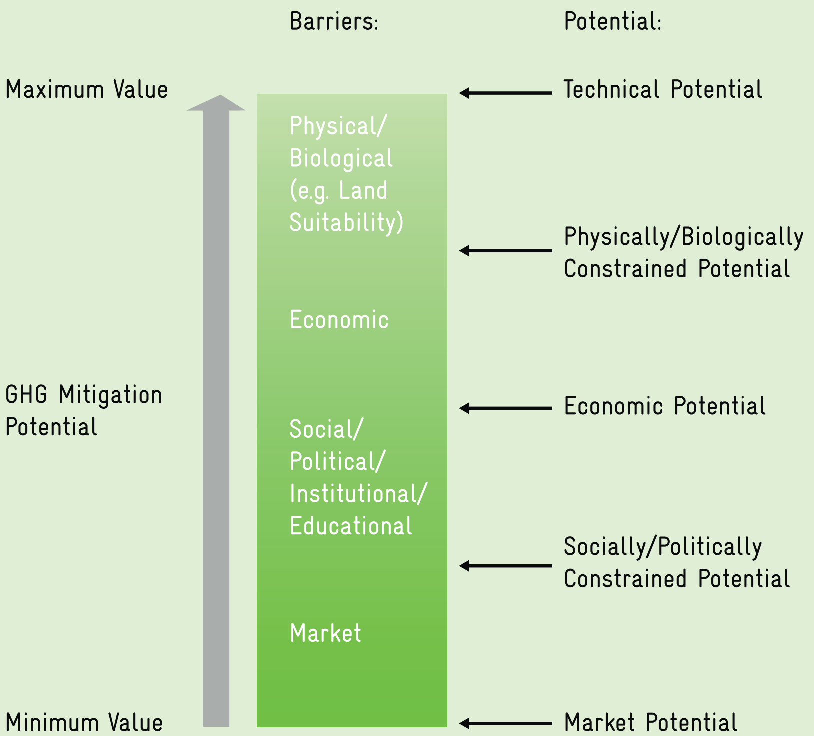
The Paris Agreement formally recognizes the role of the AFOLU sector in climate change mitigation and states that all Parties should take action to conserve and enhance GHG sinks and reservoirs. Opportunities for mitigation include reducing emissions from land use change, land management and livestock management.

Potentials of climate change mitigation (emission reduction or sequestration of carbon) within the AFOLU sector should be assessed in view of economic mitigation potentials, technical and market mitigation potentials (Smith 2012). As illustrated in Figure 16, technical mitigation potentials represent the full biophysical mitigation potential of a specific option while no economic or other constraints are accounted for. This potential is only limited by land availability and land suitability. In comparison, economic potentials refer to mitigation that could be realized at a given carbon price over a specific period, but does not take into consideration any socio-cultural or institutional barriers to adopt a specific option (Smith et al 2014).

These barriers are considered under the market potential, which represents a mitigation outcome under market conditions also considering biophysical, economic, socio-cultural and institutional barriers within a specific sub-national, national or even international climate policy context.

Figure 17 shows the economic mitigation potentials for the AFOLU sector until 2030. Total agriculture is distinguished from total forestry mitigation, and different agriculture mitigation options are shown for which estimates are available (Smith et al. 2014). The mitigation options are shown at carbon prices of up to 20, 50, and 100 USD/ tCO_2eq

Figure 16 **Relationship between technical, physical-biological, economic, social-political and market potential**



Source: Smith et al. 2014

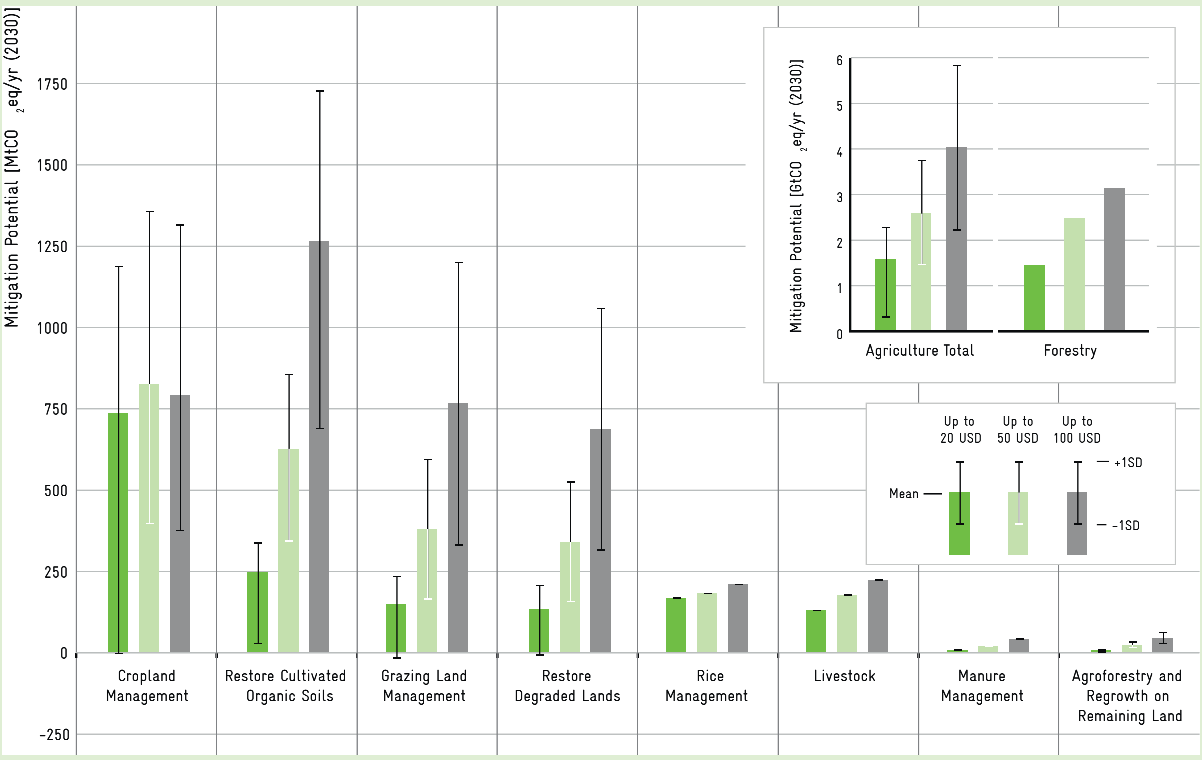
The total economic mitigation potentials for the AFOLU sector are estimated to be ~3 to ~7.2 $GtCO_2eq$/ yr in 2030 at 20 and 100 USD/ tCO_2eq, respectively. This includes only supply-side options in agriculture and a combination of supply- and demand-side options for forestry. At low carbon prices the highest mitigation potential is seen in improved cropland management and the restoration of organic soils.

Since the last IPCC Assessment Report AR4, more attention has been paid to options that reduce emissions intensity by improving the efficiency of agricultural production. Overall, the main mitigation options in the AFOLU sector are:

i. the avoidance of land-use change i.e. the conversion of peatlands, forests and grasslands into pasture or cropland;
ii. reduction of emissions and improvement of GHG emission efficiency in the livestock sector, e.g. improved feeding, range management or dietary additives;
iii. reduction of emissions and improvement of GHG emission efficiency in the agricultural sector, e.g. fertilizer and soil fertility management or tillage;
iv. better management of emissions in combined systems and agricultural value chains, e.g. post-harvest management, reduction of food wastage and demand side measures.

Among demand-side measures, which are under-researched compared to supply-side measures, changes in diet and reductions of losses in the food supply chain can have a significant, but uncertain, potential to reduce GHG emissions from food production (0.76 – 8.55 $GtCO_2eq$/yr by 2050) (Smith et al. 2014).

Figure 17 **Economic mitigation potential for the AFOLU sector. Whiskers show the range of estimates**



Source: Smith et al. 2014

There are also significant regional differences in terms of economically viable mitigation opportunities in AFOLU. Across all AFOLU options, Asia has the largest mitigation potential, followed by Latin America and Caribbean (LAM), OECD-Countries, Middle East and Africa (MAF), and Economies in Transition.

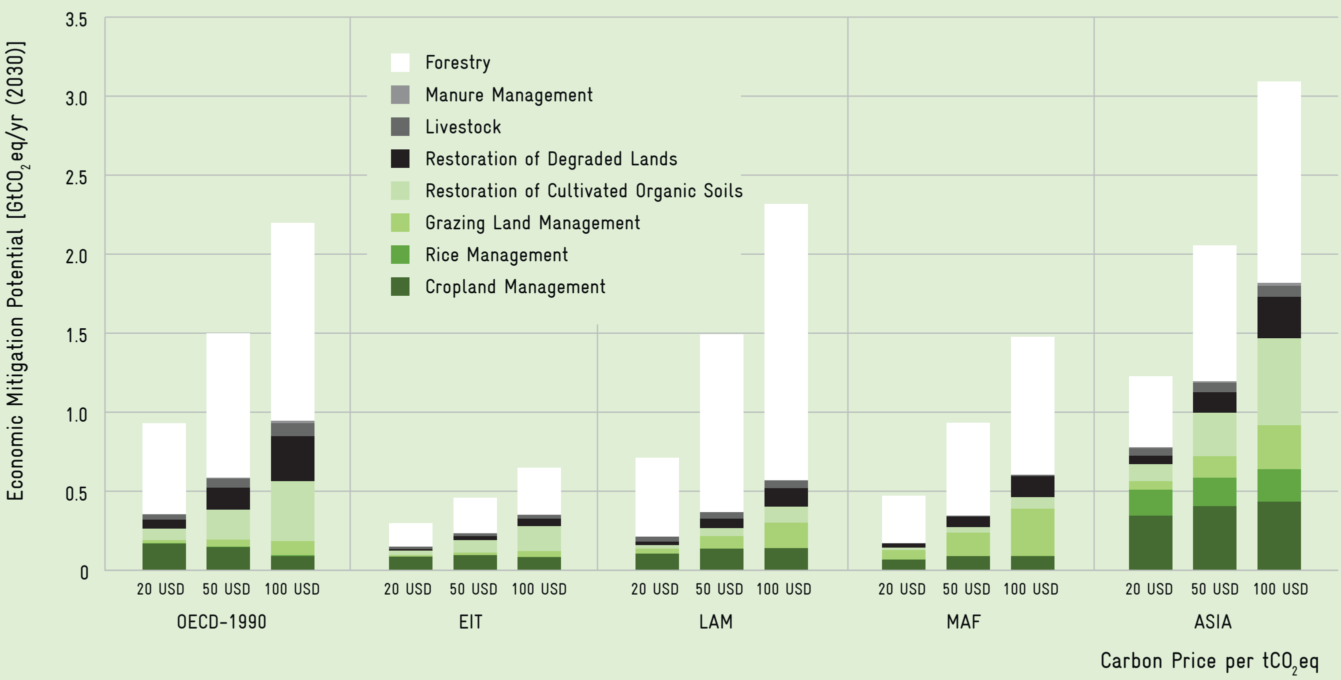
This economic mitigation potential is not considering synergies and trade-offs with the fundamental priority of safeguarding food security and ending hunger. Demand side measures, such as the reduction of food loss and wastage and the promotion of more climate-friendly diets can reduce pressure from food production on limited land.

Agricultural production is operating within three limits:

1. the amount of food that can be produced within a given climate,
2. (the amount of food that is globally needed and
3. the effect of agriculture on climate change (Figure 19).

Currently we operate outside the 'safe space', as agriculture is unsustainable and people are still undernourished. Approaches to mitigation can have an influence, moving or enlarging this safe space by increased productivity and resource efficiency, conservation of natural resources, reducing waste or shifting consumption towards low emitting animal-source foods.

Figure 18 Economic mitigation potentials in the AFOLU sector by region



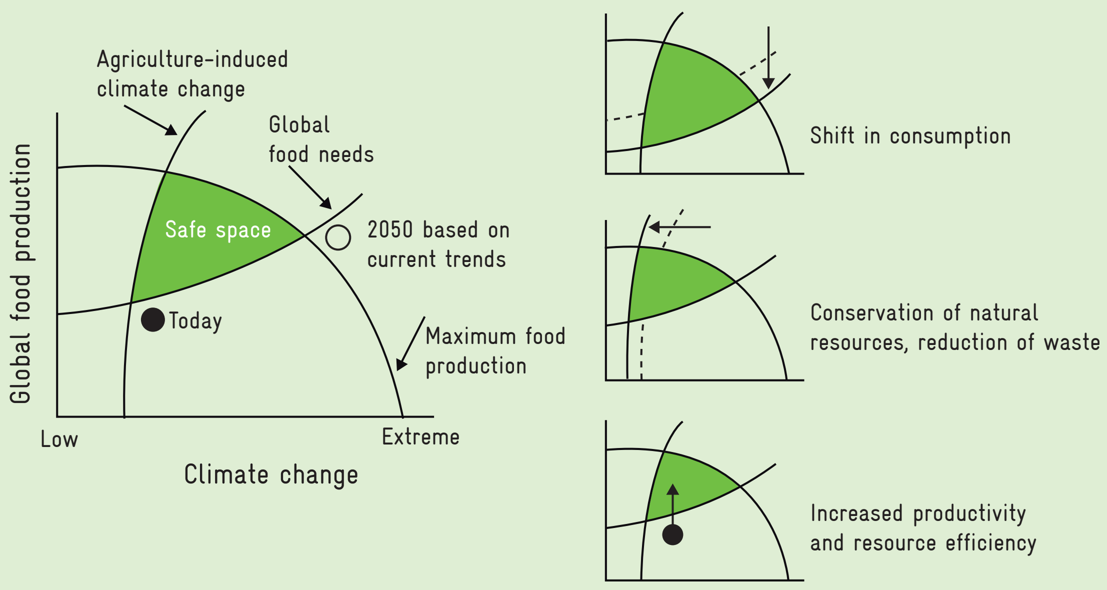
Source: Smith et al. 2014

3.2 Avoiding emissions from deforestation and restoration of degraded lands

Avoiding land-use change and keeping natural biomes intact is not only the most cost-efficient option to reduce emissions it is also crucial for biodiversity protection and to ensure that economic development serves society within the safe operating space of the biosphere.

Agriculture is the main driver of deforestation and associated emissions. A few commodities, such as beef, soy, palm oil and wood products are responsible for the majority of global deforestation. In the context of the New York Declaration on Forests (NYDF) a number of companies have made commitments in 2014 to eliminate deforestation from their supply chains and production processes until 2020. Achieving the NYDF goals could reduce the global emissions of greenhouse gases by 4.5 – 8.8 billion metric tons every year. While commitments on reducing deforestation in the palm oil and timber value chain represent over 50 % of global production, commitments to reduce deforestation related to soy and cattle are insufficient and overall the progress on zero deforestation and mobilizing public and private investment to reduce deforestation is insufficient (Climate Focus 2016, Climate Focus 2017).

Figure 19 Parameters of sustainable agricultural production



Source: Adapted from Beddington et al. 2012

Info box 2 **Toward Zero Deforestation Cotton in Zambia**

The number of companies pledging to reduce deforestation has grown rapidly in recent years. In the palm oil and wood fiber sector these companies represent a large percentage of the sector's production. Overall, it is however still a small percentage of agricultural commodity market actors.

Extreme poverty and a dependence on agriculture drive deforestation in Zambia's Eastern Province. Improving productivity through soil fertility measures is a key strategy to address deforestation, because poor production practices and soil depletion cause farmers to expand cultivation into forest areas. The root causes of declining soil fertility are poor farming practices, such as burning crop residues and repeated planting of cereals without incorporating soil enhancing crops. Extension services provided by governments, NGOs and agribusinesses tend to be very limited.

Once land productivity has declined, farmers look for new areas to cultivate, clearing forests in the process. Between 2000 and 2014 in Eastern Province, 156,000 ha of forests were lost. Maize has been the dominant crop for many years, but cotton production is increasing rapidly, driven by the increasing demand from national and international traders that export to South Africa and beyond.

Figure 20 **Typical Zambian smallholder cotton farm with low soil fertility**

In this context, the Competitive African Cotton Initiative (COMPACI) was formed by an international group of cotton companies representing US$ 65 million in annual turnover. The initiative includes four members who operate in Zambia: Alliance Ginneries, Cargill, NWK Agri Services, and Continental Ginnery. Among other social and environmental sustainability targets, COMPACI requires its members to eliminate primary forest deforestation. To achieve this goal, they must boost productivity, since farmers will not stop deforesting if it means reduced income.

COMPACI members have different ways to reach suppliers. Some employ lead farmers who advise their neighbors on improved practices. Others establish demonstration plots to promote best farm management practices in four key areas:

- inorganic fertilizers: input financing for small farmers to buy inorganic fertilizer that boosts yields;
- improved soil management practices: training on minimizing soil disturbance, preparation of planting basins, permanent organic soil cover, crop rotation;
- agroforestry: planting nitrogen fixing trees;
- integrated pest management using intercropping and molasses traps instead of chemicals.

Source: Gromko et al. 2017

Restoration of degraded soils

Reducing the pressure on already degraded or non-agricultural land requires sustainable productivity increases on the current agricultural land. Currently around 52% of agricultural lands are medium to severely degraded meaning that they do not have their optimum soil organic carbon level for production. Annually around 10 million hectares of agricultural soils are lost (FAO and ITPS 2015); most of it in Asia and Africa (Table 8).

Table 8 Degradation of soils according to regions (million hectares)

Region	Degraded area (million ha)
Afrika	660
Asien	912
Australien und Pazifik	236
Europa	65
Nordamerika	469
Südamerika	398
Total	2,740

Gibbs et al. 2015

Multiple technical and economically viable options allow to restore such degraded soils and to restore their agricultural production capacity. Their productivity can be restored through sustainable land management methods. These include e.g. soil and water conservation methods, building up of soil productivity through improved nutrient cycling, use of organic matter (manure, compost, litter) and fertilizer, integration of livestock in crop production systems, agroforestry, reduced tillage and improved fallows.

These methods will increase yields over time and thereby closing the yield gap. Yield gaps offer an important opportunity to increase food production without increasing the amount of agricultural land. Large yield gaps exist in Eastern Europe, Northern India and Northern China, parts of North America but also in Brazil, Argentina and in Sub-Sahara Africa. If the 16 most important food crops would harvest 75% of their potential yield, this would result in a 28% increase of calorie production. In case these 16 food crops are only used for human consumption (no animal feed or bioenergy), an additional 28% calories would be available compared to the present situation.

Carbon sequestration in agricultural soils is thus very important for climate change mitigation and at the same time, it enhances productivity, resilience and ecological soil health functions.

It is estimated that sustainable soil management practices and rehabilitating degraded soils could sequester annually 1.5 to 5 Gt CO_2e corresponding to 15% of the annual global GHG emissions (IPCC 2014). Agriculture with its 10-12% contribution to global GHG emissions could thereby become carbon-neutral. Whether this important sink is practically feasible remains unclear. Carbon sequestration is a long-term process depending on available biomass, temperature, soil types and prevailing soil management practices. Millions of farmers need to adopt sustainable soil management.

The safer approach is therefore to prevent soil degradation and thereby conserve the carbon in existing soil humus. Preventing the degradation and the restoration of organic soils is exceptionally important to reduce emissions and sequestering carbon. Restoring one hectare of wetland for example can sequester the same quantity of carbon as sustainable management of 50 hectare of grass- or cropland (Paustian et al. 2016).

The restoration of degraded rangeland through sustainable livestock management systems has significant carbon gains (Wilkes & Tennigkeit, 2010).

3.3 Mitigation from improved livestock management

There are a number of demand and supply side mitigation options in the livestock sector. Reducing the consumption of animal products and notably beef, has a high mitigation potential but is a sensitive topic since cultural aspects and alternative livelihoods are concerned (Haupt, et al. 2017). The projected increase in demand for animal-protein also requires the adoption of more sustainable and efficient production methods to reduce emissions and other negative environmental externalities.

Technical options to reduce emissions include improved feed management and animal health and the adoption of sustainable grassland and manure management. Feed supplements are applied in industrialized production systems to reduce methane emissions (Table 9). FAO estimates that applying practices with the lowest emission intensity (e.g. improved feed to reduce methane emissions from enteric fermentation) can reduce livestock emissions by 18–30% without reducing overall output (Gerber et al. 2013a). Most of these mitigation technologies and practices can improve productivity and thereby contribute to food security, household income, poverty alleviation and climate resilience.

Mitigation measures can be applied within an existing production system, e.g. by improving pasture quality and therewith increasing production efficiency or by shifting from one production system to another (e.g. from free grazing to stall-fed dairy production). The feasibility of mitigation measures depends on differences in production systems, availability of inputs and resources as well as the technical capacity of the farmer and the availability and quality of service and input provider. For example the use of additives, or application of

Info box 3 Energy efficiency in Kenya's dairy sector

Kenya's dairy processors are increasingly paying attention to energy efficiency in their operations. This is driven by unstable profit margins due to dynamic international milk prices and high domestic production costs, and energy efficiency requirements of newly enforced regulations on large energy consuming facilities.

An assessment of three milk processing facilities in 2016 revealed significant potential to reduce electricity consumption, as well as diesel and oil used in steam generation. The assessment also demonstrated reduced water use, use of cleaning chemicals and lower milk losses that could further reduce production costs. Measures vary from "simple" measures such as repairs of leakages or insulation of pipes, to upgrading of equipment using more efficient technologies.

Energy consumption abatement potential in the three plants assessed was between 25% – 40% of total energy demand in each plant. Due to high electricity, water and cleaning chemical cost savings, all identified measures were highly profitable.

Source: Wilkes, van Dijk and Odhong' 2017 urea to improve fodder digestibility, depend on input availability, technical know-how and associated costs. Effective mitigation measures are measures with a high GHG mitigation potential, are cost-effective and require little technical knowledge and can thus be widely practiced.

Table 9 Technical options for mitigation of livestock sector emissions

Level	Potential mitigation measures	Greenhouse gas mitigated[10]		
		Methane (CH_4)	Nitrous Oxide (N_2O)	Carbon Dioxide (CO_2)
Individual animal	Use of additives (e.g. lipids) and feed supplements	X		
	Ration balancing, inclusion of concentrate feed	X		
	Improve fodder digestibility	X		
	Animal health management (e.g. vaccination, control of tick-borne diseases), reduced animal morbidity and mortality	X	X	
Herd	Genetic selection: use of high producing and resilient animal breeds	X		
	Improve reproductive performance (e.g. age at first calving, calving or farrowing interval, litter size)	X		
	Reduction of unproductive animals, replacement rates	X	X	
	Periparturient care and animal health management	X		
	Assisted reproductive technology (e.g. artificial insemination)	X		
	Reduction of environmental stressors (e.g. heat stress, transport)	X	X	
Production system	Grazing management, managing grazing intensity (stocking rate, rotations).	X		
	Housing system (e.g. concrete floors to enable manure collection)	X	X	
	Manure storage	X	X	
	Composting	X		
	Sustainable intensification (e.g. transition from pasture-based to mixed or industrial production system)	X	X	X
Supply chain	Energy efficiency in production and processing			X
	Waste minimizing and recycling	X	X	X

Sources: Gerber et al. 2013; Gerber et al. 2013a; Gerssen-Gondelach et al. 2017; Hristov et al. 2013

3.4 Mitigation from improved cropland management

Sustainable intensification is the key on small scale farms

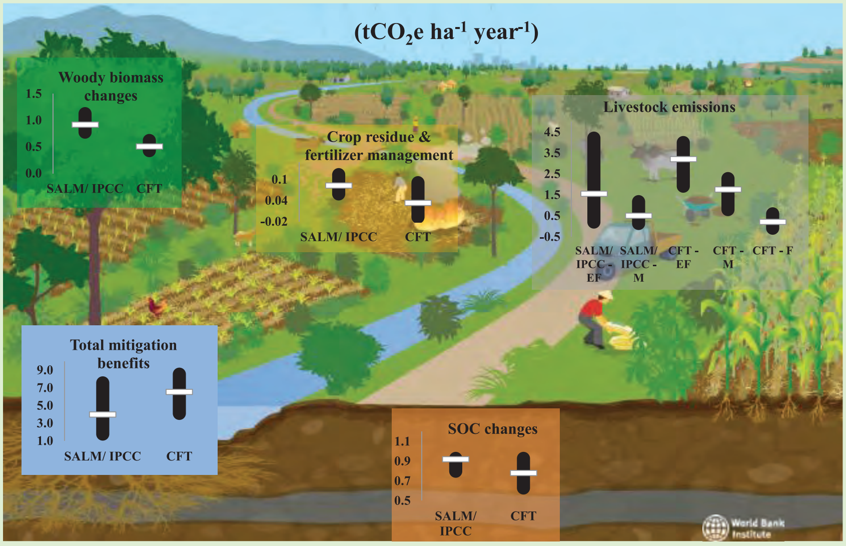
On small-scale farms, current net emissions tend to be low because farmers, except in China, use little fertilizer, pesticides, fuel powered machinery or livestock feed from external sources. At the same time, productivity is low in many cases because replenishment of nutrients and soil fertility are low. These farms either consist of mixed crops with sometimes some cash crops and some livestock for self-consumption and savings. These small farms have large potential for sustainable intensification.

What has shown success in the field is a combination of various practices of sustainable agricultural land management (SALM) on such small farms.

[10] Some mitigation measures may have positive and negative interactions with other greenhouse gas emissions. Here the main greenhouse gas mitigated is indicated.

Info box 4 **Sustainable Agriculture Land Management in Western Kenya**

In order to evaluate existing GHG quantification tools in smallholder conditions, several tools were tested with farm data from Western Kenya from the Kenya Sustainable Agricultural Land Management Project. This project is developed and implemented by the NGO, Vi Agroforestry, and registered and certified in the voluntary carbon market under the VCS Standard[11]. The project promotes 60,000 farmers, organized in 3,000 registered farmer groups on approximately 45,000 ha of agricultural land. It is breaking new ground in designing and implementing climate finance projects in the agricultural sector. While increasing agricultural productivity and enhancing resilience to climate change, smallholder farmers receive benefits for greenhouse gas mitigation based on the adoption of sustainable agricultural land management (SALM) practices such agroforestry, crop residue management, intercropping and cover crops, reduced tillage, composting, management of manure and improved livestock feeding and management (zero grazing). A farm level accounting after 2 years of project implementation was conducted using two different verified GHG accounting tools – the VCS SALM Methodology (SALM/IPCC) and the Cool Farm Tool (CFT).



Annual carbon benefits in smallholder farms in Western Kenya (tCO_2e/ha/year)
SALM/IPCC = SALM methodology and IPCC emission factors; CFT = cool farm tool;
EF = enteric fermentation; M = manure management; F = emissions from feed characteristics;
(Source: Seebauer 2014)

The whole farm quantification in 2011 compared to the baseline conditions in 2009 demonstrated the significant mitigation opportunities in smallholder crop-livestock systems if emission sources are comprehensively considered. In particular, the reduction of GHG emitted by livestock systems has enormous scope because significant reduction of methane produced by improving the quality of diets (Herrero et al. 2009) and improved management practices including grazing and manure management is possible. The farm scale quantification further showed that the adoption of SALM had a significant impact on emission reduction and removals. The mitigation benefits ranged between 4.0 and 6.5 tCO_2/ha/yr with significantly different mitigation benefits depending on typologies of the crop-livestock systems, the agricultural practices and adoption rates of improved practices. Soil carbon is important for soil structure and related nutrient and water holding properties. Hence increasing soil carbon stocks results in improved crop growth and contributes to enhance climate resilience. In addition, the increase in soil organic carbon through sustainable agricultural land management (SALM) practices such as the use of cover crops, residue management and agroforestry also reduces the need for synthetic nitrogen fertilizer at a given level of crop production.

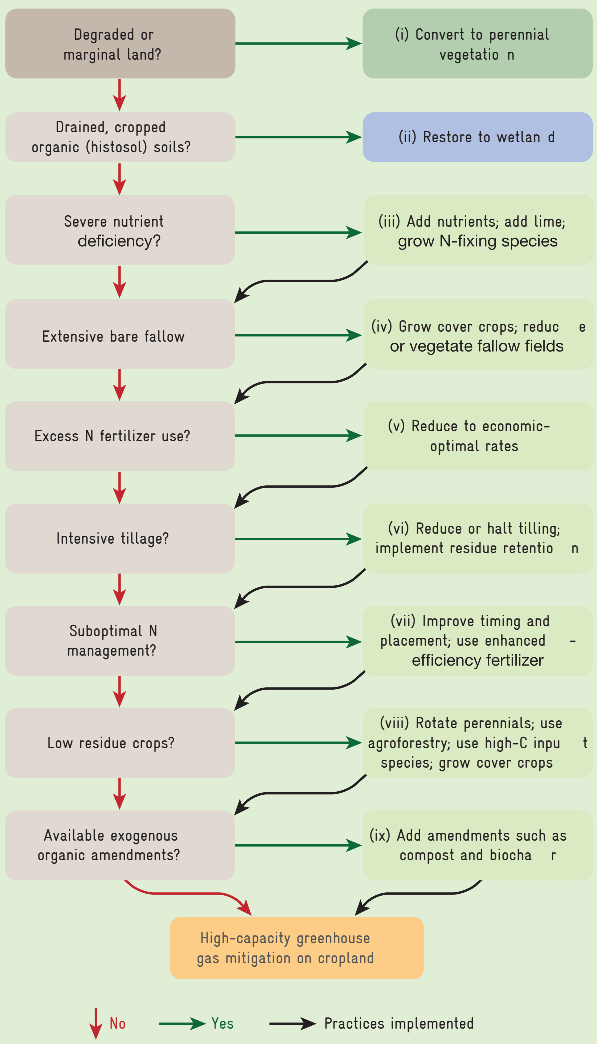
Source: Seebauer et al. 2014

[11] See http://www.vcsprojectdatabase.org/#/project_details/1225

It is of central importance in particular for developing countries to identify and adopt climate smart agriculture options that both reduce agriculture emissions and increase food production. So called 'win-win' options include soil organic carbon (SOC) sequestration and sustainable intensification. SOC sequestration through improved crop- and grassland management offers the possibility to sequester significant amounts of carbon in the soil, while at the same time improving soil quality and productivity, and subsequently food security. For example, the French government proposed in the '4 per 1000, Soils for Food Security and Climate' initiative (www.4p1000.org) to offset global anthropogenic GHG emissions by increasing the SOC content of soils annually by 0.4% through improved farming and forestry practices (Frank et al 2017). Soils constitute the largest terrestrial organic carbon pool, which is three times the amount of CO_2 currently in the atmosphere and 240 times the current annual fossil emissions. Thus increasing net soil carbon storage by even a few per mille represents a substantial carbon sink potential. However, the doubts abouts practical feasibility to use this potential have already been discussed in chapter 3.2.

Paustian et al. (2016) has summarized potential cropland mitigation practices in from of a decision tree shown in Figure 21 below.

Figure 21 Decision tree for cropland GHG mitigation actions



Source: Paustian et al. 2016

Improved rice production

The System of Rice Intensification (SRI) or Alternative Wetting and Drying (AWD) are reducing emissions in rice production by changing the management of plants and inputs, i.e. soil, water and nutrients. The main components are healthy plant establishment, reduced plant density, improved soil conditions through enrichment with organic matter and reduced and controlled water application. SRI proves to emit up to 22% less methane than conventional paddy rice production (Dill et al. 2013, Nguyen et al. 2008).

Demonstration trials and training have been conducted in eight countries in Asia, with large scale adoption in the Philippines, Vietnam and Bangladesh. A thorough review (Lampayan et al. 2015) concludes that AWD has reduced irrigation water input by up to 38% with no yield reductions if implemented correctly.

Info box 5 Benefits of Climate Smart Rice in Northern Vietnam

Ba Thuoc is a poor district in western Thanh Hoa province in Vietnam with more than 4,000 ha of paddy rice. Rice is the major staple food of the local people and rice farmers traditionally cultivated rice with high planting density, high use of fresh manure, and frequent applications of chemical fertilizers. These practices polluted the water and land, caused GHG emissions and produced relatively low yields and returns considering the investment in seed, fertilizer, and other inputs.

Vietnam Forest and Deltas Program cooperated with Ba Thuoc District People's Committee to apply climate smart rice techniques in four communes through farmer field schools, promoting:

- planting rice seedlings in lower densities than in traditional methods
- limiting water levels in paddy areas in order to reduce greenhouse gas emissions; and
- utilizing straw as an alternative to chemical fertilizer.

The benefits of climate smart rice cultivation have so far surpassed those of conventional rice cultivation in the following areas:

Economic

- Yields have increased by 20-30% when applying climate smart methods,
- The amount of required seed is reduced, thus saving farmers money in seed costs.

Environmental

- 50% reduction in chemical fertilizer use (associated cost saving not calculated);
- Water usage has been reduced to about 30-50% of the original amount;

(- GHG emission savings due to shorter inundation periods have not been measured for this specific case.)

Source: Vietnam Forests and Deltas Program (2017): Climate-smart rice supports livelihoods and the environment.

Less inputs, more sustainable outputs on larger farms

On larger, mechanized farms, there is more specialization in production and input intensity is higher, resulting in higher yield efficiencies but also higher net GHG emissions especially due to higher fertilizer and fossil fuel use. Further productivity increases in this type of agriculture are still possible, but the productivity gain is relatively smaller compared to the overall output and is harder to achieve without additional inputs. Mitigation measures at this end of the agricultural production spectrum are therefore better aimed at improving input efficiencies.

Since nitrogen fertilizer use is unanimously identified as the main source of GHG emissions from crop production, a promising mitigation measure is to focus on increasing fertilizer use efficiency on farms that currently overuse.

Historic increases in agricultural production came at the expense of substantial environmental burden among others through nitrogen. There is a dilemma between increased agricultural production and risk of water pollution and increased GHG emissions due to excessive nitrogene use. A review in China indicates that the same crop yields can be achieved with 20-30% less fertilizer input Kahrl et al. (2010).

Improving overall nitrogen use efficiency globally is one of the key mitigation options in the agricultural sector and can be achieved through a combination of regulatory policies and technology deployment (Bodirsky and Müller 2014).

Moving the technology frontier: History has shown that production practices can change. In Europe, yields increased simultaneously with reduced fertilizer inputs after the 1980s, when the Nitrates Directive was passed. Such shifts in the production frontier can be reached through better nutrient management, providing the nutrients to the plant in the right amount, at the right place, in the right time, and as the right type of fertilizer. These nutrient specific management improvements can be further amended by improved plant breeds, water management, or protection from pest and diseases to further increase efficiencies.

Re-allocating nitrogen fertilizer use globally: Nitrogen intensity of production varies strongly between countries. Reducing nitrogen overuse while at the same time increasing the targeted application in regions where fertilizer is hardly used, bears a large potential to improve global nitrogen use efficiency. An optimal nitrogen allocation between countries could decrease excess nitrogen by 49%– 67% while holding global production constant.

Emissions from energy use on-farm are relatively minor as compared to other farm emissions, but grow in importance on larger, more mechanized farms and systems with higher input intensities. Clean energy solutions to substitute fossil fuel sources are another promising mitigation intervention on this type of farms (Info-box 6).

3.5 Combined systems

In many regions around the world, tropical forest areas continue to decline. However, the opposite appears to be true on existing agricultural land, where tree cover has increased moderately in some regions, capturing nearly 0.75 Gigatons of carbon dioxide each year over the past decade (Zomer et al. 2016). Combined systems[12] have the potential to contribute to climate change mitigation while increasing resilience and improving livelihoods and incomes and providing important ecosystem services. There are an estimated 1.2 billion people that use agroforestry farming systems, particularly in developing countries. Significant differences exist however. The distribution of tree cover on agricultural land depends on climatic conditions in different parts of the world. A high tree cover percentage can typically be found in humid areas with plantation systems, while tree cover is moderate to low in drier regions.

Tree cover therefore makes an important contribution to carbon pools on agricultural land, demonstrating the potential to mitigate climate change as well as contribute to adaptation efforts. On the other hand, the large amount of agricultural land with less tree cover constitutes a huge mitigation potential, which can be explored systematically.

In South America in areas with a low population density, historic land use patterns e.g. have resulted in a widely adopted dual system of extensive cattle grazing next to commercial cropping systems.

[12] Agroforestry systems combine agricultural production with tree production for timber or non-timber products, silvo-pastoral systems combine livestock rearing with tree production on either a temporal or spatial scale. Less common, agro-silvo-pastoral systems combine all three production schemes.

Info box 6 Solar-powered irrigation in East Africa

While the majority of farmland in Africa is rain-fed, 6 % of the farmland is under irrigation. Irrigation often relies on energy intensive and expensive diesel pumps, which contribute to greenhouse gas emissions. To address this challenge, solar startup SunCulture from Kenya received a Powering Agriculture award for the early adoption and dissemination of tailored Agro-Solar Irrigation Kits to smallholder farmers.

The irrigation kit combines cost-effective solar pumping technology with a high-efficiency drip irrigation system to make crop production cheaper and easier. The kit pulls water from any water source (lake, well, etc.) using solar power. The solar panels provide the pump's electricity directly without the need for expensive batteries or inverters. Water is pumped into a raised water storage tank during the day and released in the evening through an irrigation tube.

The benefits for farmers include increased production of higher value produce, cost savings, and more efficient use of time. Time saved on farming and water gathering can be directed to other more productive activities. Environmental benefits include water savings and emission reductions.

The kit is available in Kenya for 50,000 Kenyan Shillings ($480). Using it can help boost a farmer's income from less than 300,000 Kenyan Shillings ($2,884) relying on rainfall to 1.2 million Kenyan Shillings ($11,538) annually. The numbers help illustrate the main implementation barrier of relatively high upfront investment costs (15% of the baseline income) combined with the need for training.

Source: https://poweringag.org/innovators/scaling-distribution-tailored-agro-solar-irrigation-kits-smallholder-farmers

Info box 7 Mitigation impact and other benefits of silvo-pastoral production in Paraguay

A case study in Paraguay compares silvopastoral production with production systems encompassing either solely beef or solely plantation forestry, through three performance lenses: economic, environmental and social impact. The results are summarized in the following table.

Table 10 Advantages and disadvantages of combined systems versus monocultures

	ADVANTAGES	DISADVANTAGES
ECONOMIC	▸ Combination of the production of goods in different time horizons. ▸ More attractive returns than pure livestock production systems.	▸ Higher initial investments when compared to beef production.
TECHNICAL AND PRODUCTIVE	▸ Increased animal welfare and productivity provided by shade. ▸ Increased moisture retention and grass quality. ▸ Cattle provides weed and fire control, reducing costs for forestry production.	▸ Increased complexity when compared to monocultures. ▸ Lower production volumes of forest and animal products when combined compared to traditional systems. ▸ Competition between trees and grass. ▸ Cattle might cause damage on trees.
ENVIRONMENTAL	▸ Increased carbon benefits compared to pure livestock systems. ▸ Erosion control and increased watershed protection compared to livestock and sometimes pure plantations.	
SOCIAL AND CULTURAL	▸ The combined system provides more employment when compared to beef production system.	▸ Complexity and unfamiliarity are a disadvantage for traditional producers.

Source: Adapted from Braun et al. 2016

Economically, silvopastoral systems allow for the production of different goods on different time horizons, diversifying incomes for the producer. From a technical and point of view, silvopastoral systems, as any combined systems, increase complexity and the need for technical knowledge when compared to monocultures, which is the reason why the latter is usually preferred, particularly by large producers.

The social impact in terms of job creation is considerable when introducing forestry on grazing land. Experiences around the world show that a traditional forestry plantation of 1,000 ha provides between 20 and 80 full time positions throughout the whole cycle, whereas cattle ranching on the same area provides between 1 and 3 full time positions. While both value chains are traditionally male dominated in the region, tree seedling production in nurseries typically introduces jobs perceived as attractive for the female labor force in rural areas.

From an environmental point of view, silvopastoral systems have shown to provide erosion control and can be more effective in terms of watershed protection as opposed to pure livestock and forestry systems. For biodiversity, the effect is highly dependent on the baseline scenario. On land previously used for agriculture or implanted pastures, silvopastoral systems provide opportunities for improvements, as has been shown in Colombia (Rivera et al. 2016).

Forestry also sequesters carbon and might even compensate for the emissions caused by cattle. For a concrete farm on 6,000 ha in Paraguay, the carbon footprint (emissions – sequestration potential) of production scenarios was calculated. Pure beef production, which is the baseline, results in net carbon emissions of 1.8 tons CO_2e/ha/year. The combined system however sequesters carbon at a rate of 2.8 tons CO_2e/ha/year with a production emphasis on beef, and 5.3 tons CO_2e/ha/year with a production emphasis on timber.

Source: Braun et al. 2016: Upscaling silvopastoral systems in South America. IDB-IIC.

However, in recent decades export-oriented industrial agriculture has become a main driver of land use change, increasing the pressure for more efficient and intensive production systems.

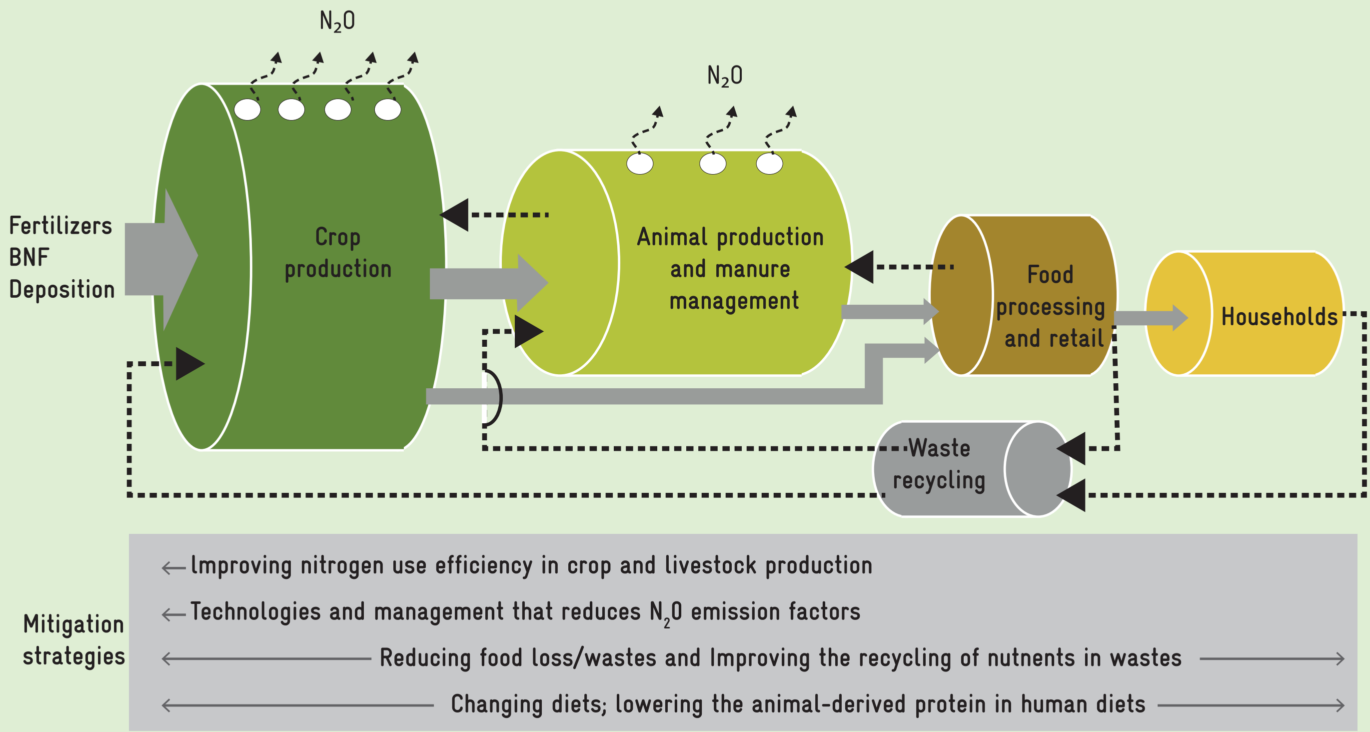
Silvopastoral systems, combining livestock (mostly beef cattle) and timber production can offer an attractive alternative land use in this context. While economic, environmental and social benefits of silvopastoral systems have been described in the literature, the adoption of these systems in South America is still limited. This can be partially attributed to the lack of technical knowledge and the associated risks (Braun et al. 2016).

The newly emerging concept of Forest (and) Landscape Restoration (FLR) is the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes. FLR manifests through different processes such as new tree plantings, managed natural regeneration, agroforestry, or improved land management to accommodate a mosaic of land uses, including agriculture, protected wildlife reserves, managed plantations, riverside plantings and more. According to a global assessment of restoration potential, there are about 1.5 billion hectares of deforested and degraded land around the world where opportunities for some type of sustainable land use intervention may be realized (IUCN & WRI 2017).

3.6 Reducing GHGs in agricultural value chains

To feed another two billion people in 2050, food production will need to increase by 50 % globally. This means that GHG emissions from the global agricultural sector will continue to increase in the future, while

Figure 22 Economic mitigation potentials in the AFOLU sector by region



Source: Oenema et al. 2014

the emissions intensity of a given food item will have to decrease. This requires systemic mitigation efforts that take into account entire agricultural value chains.

In agricultural value chains, efficiency can be achieved by producing more per area of land or with less input e.g. by reducing the rotation age of cattle or crops and by reducing food loss and waste.

Improvements in the value chain can be introduced upstream in the agricultural supply industry and agricultural production or downstream during processing and consumption.

Figure 22 gives a simplified overview of possible efficiency interventions at various stages of the agri-food system downstream from primary production.

Upstream measures reduce emission intensity of farm inputs including fertilizer, machinery and sourced primary products like seedlings, young animals or feed. In global agricultural value chains, upstream measures of one value chain actor are typically the production stage measures of a smaller, more localized actor. Two entry points to improve efficiencies could be possible: Measures can be introduced in the agri-manufacturing industry (e.g fertilizer manufacturers) with regard to more efficient use of energy and resources. Or resource efficiency can be improved on farms that are "upstream" in global value chains (e.g. seedling producers, local herders growing young cattle and selling them to fattening stations.

Downstream, energy efficiency in processing is a promising entry point for emission reduction and development, since expanding access to clean energy in the agricultural sector of low-income countries is a key to address food security and economic growth. Additionally, it provides a clear business case to the participating farmers or processing enterprises, especially in countries with high energy costs or remote areas where a connection to the grid would be prohibitively expensive. Significant barriers hinder the uptake of clean energy technology however and must be addressed. Such barriers include:

- high upfront investment costs
- lack of investment grade, site specific feasibility studies (lack of expertise in conducting it or lack of financial resources to pay for such a study)
- perceived performance risk of new technologies
- lack of knowledge about new technologies on both implementer and investor side
- commercial banks reluctant to finance such investments without public risk mitigation instruments

The initiative Powering Agriculture is an example that addresses implementation barriers of clean energy solutions in primary production and processing. Initiated by USAID, the German and Swedish Governments and other partners, the program implements on-farm and close-to-farm-gate interventions in clean energy.

Complimentarily, a number of public and private financing mechanisms exist that aim to address the technical and financial barriers of clean energy investments in small to large scale agribusinesses:

- The Eco Business Fund (http://www.ecobusiness.fund)
- The Inter American Investment Corporation's various concessional clean energy funds (http://www.iic.org/en/blended-climate-funds/programs)
- The EBRD implemented FINTECC program (http://fintecc.ebrd.com/index.html)

They all aim to help companies with necessary technical feasibility studies and tailored loans designed to bridge high upfront investment costs and longer than usual payback periods of clean energy technologies.

As described earlier, most GHG emissions along the agricultural value chain after production arise from food losses and waste (FLW). Therefore, promising mitigation benefits can arise from interventions targeted at reducing loss and waste along the food supply chain (Figure 23).

Nash et al. 2017 investigated FLW interventions in 12 developing countries across different value chains. Potential reductions in FLW varied greatly by product and ranged from 2 to 40% in the dairy sector, which represented the highest savings potential. Savings in maize were 2-20%, 18-20% in horticulture and fruits, and 3-15% in rice. Associated GHG savings were also calculated but are not available as disaggregated data.

Info box 8 Energy efficiency in tea processing

Kenya is the world's top exporter of black tea by weight. 60% of Kenyan tea is produced by 560,000 smallholders, supplying their tea to the Kenya Tea Development Agency (KTDA), who is the biggest employer in Kenya. Their processing facilities are located at the tea plantations with access to grid electricity, but frequent power cuts lead to reliance on fossil fuel powered generators. Tea processing is very energy intensive, costly and unsustainable due to the use of furnace oil and wood biomass for tea drying. Therefore, it offers significant energy saving potential. To tap this potential, KTDA, Ethical Tea Partnership, Taylor's of Harrogate and GIZ Powering Agriculture started implementing an energy efficiency program including energy audits and training. The first eleven factories that received audits, training and recommendations for energy efficiency measures were able to reduce electricity consumption by 11% on average, and firewood consumption by 10%. This means annual energy cost savings of 7 million Kenyan Shillings per factory.

Energy audits provided insight into the most significant issues in energy consumption regarding patterns and thermal energy. Useful economic recommendations both for the tea factories concerned and for energy management in general were made. As a result, factories implemented several recommended energy efficiency upgrades, such as:

- Replacing fans
- Installing pre-heaters
- Withering system upgrade
- Construction of drying sheds
- Installing a briquette machine
- Insulation of pipes
- Improvement of dryers
- Improvement of the energy management system
- Energy saving light bulbs

Source: GIZ Powering Agriculture 2017: Pilot Project 'Energy Efficiency in Kenyan Tea Factories & Energy Auditing in Tea and Dairy Industries'

Regarding demand side measures, Kiff et al. 2016 assessed the extent to which demand-side policies and measures are readily available. Often discussed demand-side measures include 'soft' measures, e.g. health promotion initiatives, product labeling, and 'hard' measures such as consumption taxes or subsidies. The report reviews available evidence on the effectiveness of these measures with a focus on developing countries. The challenge is that evidence of the effectiveness of measures is scarce or even non-existent, potentially keeping regulators from implementing them. A few examples exist however.

In the livestock sector, demand side measures have theoretically a higher mitigation potential than technical measures. This assumption is based on studies that looked at GHG savings effects of assumed dietary change as compared to improved cropland or livestock management. For example, emissions could decrease by as much as 51% with decreased global meat consumption, whereas technical interventions at production level would still results in a 13% emissions increase compared to the baseline (Popp et al. 2010). It is acknowledged that "considerable cultural and social barriers against a widespread adoption of dietary changes to low-GHG food may be expected" (Smith et al. 2014).

Figure 23 Examples of food loss and waste interventions along the food supply chain

Input Choice	Harvesting	Processing	Storage	Transportation
Select crop varieties that have longer shelf life, meet buyer quality requirements, and have improved drought or salinity tolerance. Select crop and livestock types, species or breeds that disease tolerant.	Plan cultivation schedules to time harvest for maximum shelf life. Improve physical handling to reduce physical deterioration of products. Sort freshly harvested items to separate damage crops from undamaged crops.	Modify the product's form or make-up for longer preservation. Dry product to achieve optimal moisture levels for storage. Reduce contamination through use of proper practices, standards, and tools.	Maintain hygiene during food handling and storage through improved packaging. Promoting of climate controlled facilities and units. Maintain cold chain from harvest to retail. Utilize pest and contamination practices.	Improve infrastructure for physical travel. Develop centralized distribution facilities. Schedule transportation for ideal storage conditions for products while in transit.

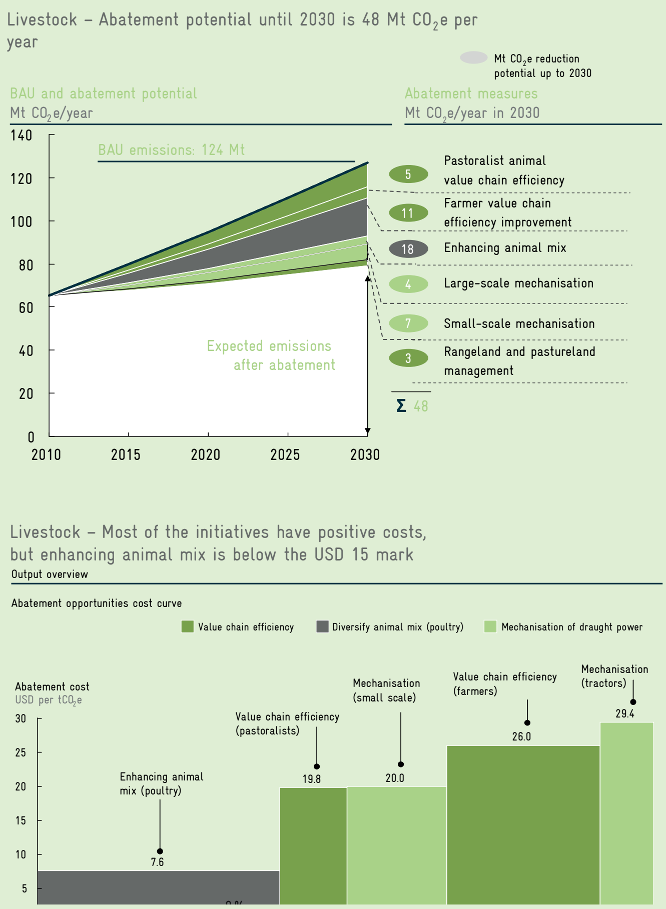
Source: Nash et al. 2017

Info box 9 Supporting animal mix diversification in Ethiopia

A rare example of a policy initiative targeting consumption patterns in a developing country is Ethiopia's Green Economy Strategy that supports the consumption of low emitting sources of protein, to reduce emissions from its growing livestock sector (Federal Democratic Republic of Ethiopia, 2011). The underlying logic is that although meat is an important source of nutrients, consumption of (processed) meat is associated with a range of health risks. Promoting production and consumption of less resource- and GHG-intensive livestock types can change the emissions trajectory of the livestock sector, and may also have other environmental and health benefits.

Livestock plays an important role in the national economy both in terms of GDP and income for a large number of families. The sector is expected to expand even faster than population growth, with a projected doubling of livestock-related emissions by 2030 (mainly from enteric fermentation of cattle). To prevent this, the initiative supports the increase in production and consumption of lower-emitting species such as poultry, sheep, goat and fish by acting both on supply and demand aspects. The primary element of the animal mix lever is increasing poultry to 30% of meat consumption by 2030. Out of all the initiatives within Ethiopia's high emitting livestock sector, this initiative has the largest abatement potential in the Livestock sector, amounting to 17.7 Mt CO2e in 2030 while at the same time having the lowest cost of all planned measures (Figure 24).

Figure 24 Mitigation potential and cost per tCO_2e of livestock sector mitigation measures



Source: Federal Democratic Republic of Ethiopia, 2011

Overall, the feasible mitigation potential of demand-side measures might be lower than current estimates of the technical mitigation potential. Evidence on the feasibility and effectiveness of demand-side measures in developing countries is very limited, and evidence from developed countries suggests that the feasible mitigation potential of demand-side measures is likely to be significantly lower than current estimates of the technical mitigation potential, mainly because consumer behavior is challenging to influence. More research is needed to quantify demand-side GHG mitigation potential; to identify supportive contexts for developing policy approaches; to support collaboration among value-chain actors; and to enable private sector investment (Kiff et al. 2016).

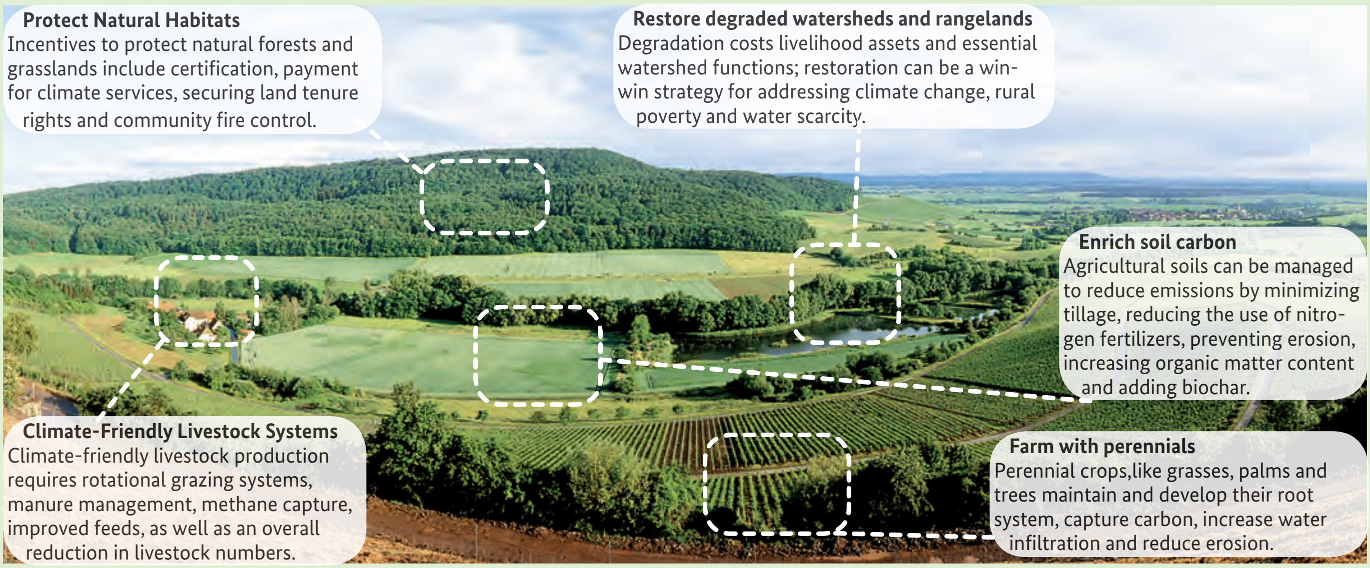
3.7 Co-benefits of mitigation

The concept of Climate Smart Agriculture (CSA) has emerged at the international level in 2009 and has been defined in 2010 by FAO (FAO, 2010). It summarizes the following three objectives:

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

The possible trade-offs between the three objectives, and the potential to increase synergies amongst them through policies, institutions and financing was a key feature of the CSA concept

Figure 25 Components of a climate-smart landscape



Source: adapted from Scherr et al. 2012

Which is widely used by international organizations such as the World Bank, IFAD and CGIAR.

CSA has since evolved and the term was more comprehensively defined e.g. in the CSA Sourcebook in 2013. Later on the term climate-smart landscape approach evolved (Scherr et al. 2012) as a more holistic landscape approach integrating the following elements:

1. Climate-smart landscape interventions are designed to achieve multiple objectives including human well-being, sustainable food and fiber 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, 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 Figure 25.

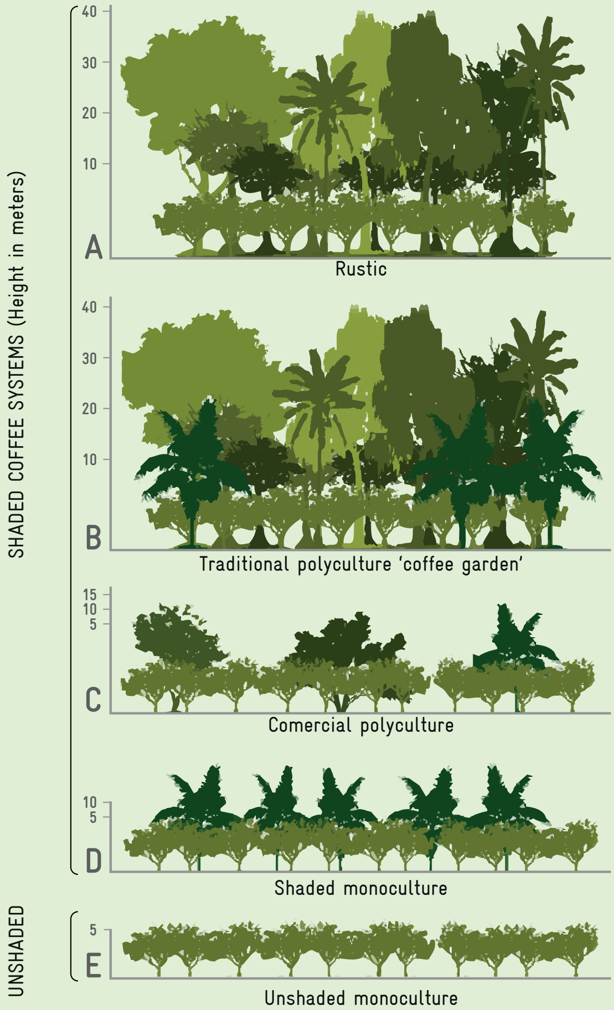
Environmental co-benefits: more than carbon

In the land use sectors, synergies between climate change mitigation and adaptation measures and other environmental and social benefits are more important than the trade-offs between them. Soil organic carbon, is widely acknowledged in agricultural scientific literature as a good proxy indicator for many other environmental co-benefits. Increased soil organic carbon also improves the water retention capacity, nutrient availability and biodiversity of soils and decreases soil erosion. As a result, productivity and overall system resilience are increased. Soil carbon has also been discussed as proxy indicator for biodiversity, water quality, food and nutritional security as well as plant, animal and human health (Lal 2015).

Info box 10 **the carbon content of coffee systems and associated environmental benefits**

A good example of a direct correlation between the carbon content of a system (soil organic carbon + above ground carbon) and environmental co-benefits such as biodiversity and ecosystem resilience are coffee production systems.

Figure 26 **Gradient of coffee production systems in Mexico**



Coffee production systems in Central America represent a gradient from the most traditional, low input, small scale, structurally diverse systems to the least diverse and most input intensive industrialized systems. Within the combined systems, one has to differentiate between natural forests that are transformed into managed forests (top two systems) and commercial polycultures with non-native introduced species as cash crops.

Trees regulate the micro-climate, increase soil fertility, soil water content and soil biodiversity. In addition, a diverse shade canopy creates habitat for fauna and increases the overall carbon sequestration potential of the system.

Therefore, supporting the maintenance, renewal and economic feasibility of shaded coffee plantations is a mitigation measure with multiple environmental co-benefits. Yields are higher in unshaded commercial systems but they are not suitable to more premium coffee varieties. The new establishment of shaded coffee plantation can be beneficial in areas, where less carbon rich systems are replaced.

Source: Based on Moguel &Toledo 1999

Water savings by improved irrigation techniques leaves more available water for natural vegetation, wildlife and downstream users. Alternate-wetting and drying (AWD) and the system of rice intensification (SRI) save water and additionally reduce methane emissions from rice fields. Other water saving technologies like replacing flood or pivot irrigation with drip irrigation systems, are usually accounted for as adaptation measures.

The International Finance Corporation (IFC) has started recognizing pure water savings projects as mitigation activities, even without on-site energy savings, due to research that shows that water savings can lead to energy savings at the macro level (EPA 2017).

Social and economic benefits

The most tangible benefits of many mitigation measures are economic in nature i.e. higher incomes for farmers and additional jobs on larger farms and in value chains. In line with more income and labor, social benefits may increase e.g. well-being, health and educational effects.

Taking the above example of AWD in Asia, the decrease in water pumping expenses and fuel consumption result in an income increases of up-to 38% in Bangladesh, 32% in the Philippines, and 17% in southern Vietnam (Lampayan et al 2015).

Socio-economic synergies with mitigation practices often exist but this strongly depends on the context. An illustrative study in Paraguay compared the labor requirements of a traditional forestry plantation and cattle ranching. A forestry plantation of 1,000 ha provides between 20 and 80 full time positions throughout the whole cycle, whereas cattle ranching on the same area provided between one and three full time positions in the same time (Braun et al. 2016, see info box 7). Soil organic and above ground carbon stocks are also significantly higher in the forestry plantation.

Whether the added income and additional jobs benefit all parts of the population equally, is a different question altogether and applies to all development projects beyond the agricultural mitigation realm. A common challenge of many mitigation measures is the high knowledge requirement for implementation, which often acts as the main uptake barrier. When designing capacity building programs an important factor to keep in mind is that disadvantaged groups tend to have less access to information to begin with and might be less likely to participate in new knowledge development.

Improving benefits for women

Within the international climate debate, there has been an increasing recognition of the disproportionate impacts of climate change on women and girls and a growing awareness of the social, economic, and climate benefits of advancing gender equality and women's empowerment. Women tend to be more at risk from climate change than men because they represent the majority of the world's poor (UNDP 2012). Female farmers often produce less than their male counterparts because they have less access to or ownership of land, use fewer inputs and have less access to important services such as extension services. In many countries, women are only half as likely as men to use fertilizers. Consequently, if women had the same access to productive resources as men, they could increase yields on their farms by 20–30% (FAO 2011). Another reason to specifically target women is that more and more agricultural work is being done by women, as men move to non-farm jobs. In all parts of the world except Europe, the proportion of women in the total agricultural work force has risen over the past four decades (Doss 2011).

In general, gender mainstreaming in agricultural mitigation projects should aim at shedding light onto the following aspects:

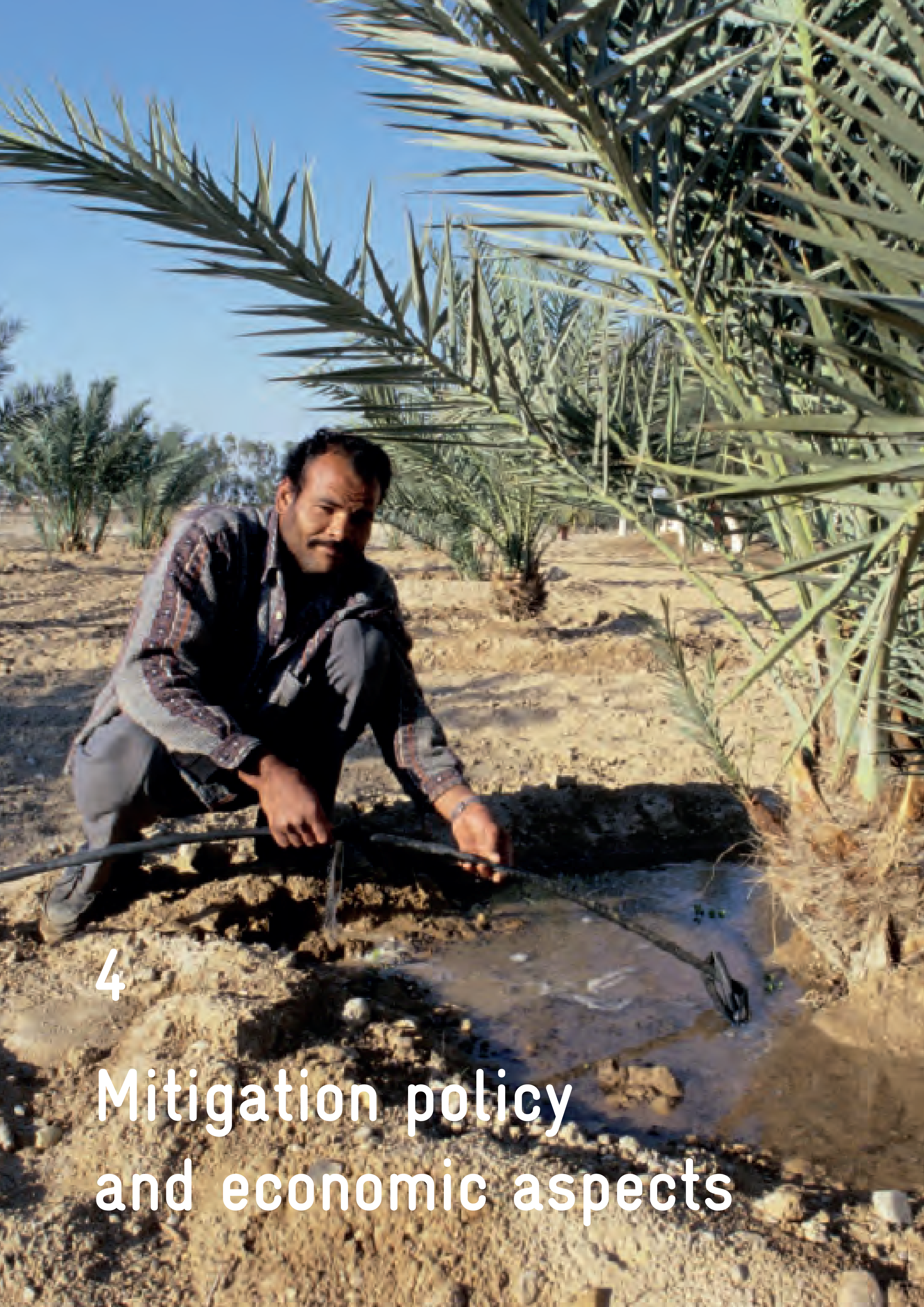
- What are the gender issues in access to production factors (land, inputs, labor)?
- What are the costs and benefits of a given mitigation measure for women?
- How do gender issues affect adoption rates?
- How has gender been addressed in dissemination initiatives, including financing?
- How is gender addressed in related policies?

Paradoxically, people who might benefit most from certain mitigation measures are at the same time often least likely to know about and adapt such measures (Wilkes & Van Dijk 2017). An example is the adoption of clean energy solutions in smallholder dairy households in Kenya. Manure provides an ideal feedstock for domestic biogas in these households, but women are often not involved in decisions about investments and technology uptake. Women are more likely to be involved in the purchase of traditional fuel sources such as fuel wood, charcoal and kerosene. They are also the ones who benefit more from clean energy sources in the household in terms of reduced exposure to air pollution, reduced time and labor for energy provisioning.

For the adoption of any new technology, it is important to consider that:

- although women may be the main user of a certain technology or practice, they are not necessarily the main decision maker in a household;
- male household heads may not consider the benefits of technology adoption, particularly the benefits for women;
- men often control the resources required for the adoption of a new technology; and
- gender disparities in access to information may impact on adoption decisions.

These situations may result in non-adoption of a certain measure even if women in the household are willing to adopt.



4

Mitigation policy and economic aspects

4.1 Agricultural mitigation policy issues

The Paris Agreement, recognizes the fundamental importance of food security, ending hunger, and taking into account the vulnerabilities of food production systems.

In more than 90% of all Nationally Determined Contributions (NDCs), the agricultural sector is mentioned related to mitigation and adaptation goals. 94% of all developing countries have defined contributions in the field of adapting. 69% of all countries have identified political and operational measures in the agricultural sector related to mitigation. 31 out of 189 countries (16%) explicitly refer to climate-smart agriculture (FAO 2016).

The COP23 in Bonn, Germany, agreed for the first time to address issues related to agriculture in the the Subsidiary Body for Implementation (SBI) and the Subsidiary Body for Scientific and Technological Advice (SBSTA). This actually constitutes a break-through in dealing with agriculture under the Convention. As a result of the decision, the Koronivia Joint Work on Agriculture (KJWA) was established, signaling support on all sides for an agricultural transformation. The KJWA presents an opportunity for countries to work together to ensure that agricultural development will reach both; increased food security in the face of climate change, and a reduction in emissions.

The Global Alliance on Climate Smart Agriculture (GACSA) is an important multi-stakeholder platform to foster the adoption of climate-smart agriculture. It is hosted by the FAO and provides a knowledge exchange forum for interested stakeholders.

At the regional level, e.g. the Africa Climate Smart Agriculture Alliance has been launched in 2014 to facilitate multi-sectoral in-country engagement and collaboration, and to support the development of national CSA plans. It was the first forum at a continental level, highlighting the importance of the approach for African agriculture.

4.2 Economics of agricultural mitigation

Financial mechanisms set up to compensate developing countries for their efforts in (voluntarily) mitigating GHG emissions were so far not able to bring agricultural mitigation measures to scale. Experience has shown that mitigation for mitigation's sake does not work, unless the implemented measures have clear other economic, social and environmental co-benefits. Few flagship agricultural carbon projects such as the Kenyan Agricultural Carbon Project (Info box 4) have managed to deliver financial benefits to smallholder farmers engaging in carbon increasing practices. The revenues from carbon certification however barely cover implementation costs and represent a small add-on to participating farmers. The real economic benefits for farmers lie in yield increases due to increased soil fertility and overall better farm management.

The following table (Table 11) gives an overview of study results that have looked into some of the economic costs and benefits of mitigation measures at farm level.

Table 11 Economic costs and benefits of farm level mitigation measures across example commodities and geographies

Mitigation practice	Production system	Country	Upfront investment	GHG savings	Yield increase	Economic return	Main implementation barrier
Optimized nitrogen fertilizer management							
Shift from urea to ammonium sulfate/ nitrate	Maize	India	No data	No data	5–11%	Cost prohibitive	No data
	Wheat	Mexico	No data	No data	11% or 0.76 t/ha	Cost prohibitive	No data
Optimization of N fertilizer application rate with optical sensors	Wheat, rice	India	No data	0.016–0.061 tCO_2e/ha (wheat); 0.051–0.247 tCO_2e/ha (rice)	10%, or 0.2–0.53 t/ha (wheat); no change for rice	Increase in net returns $159/ha for wheat	No data
	Wheat, maize	Mexico	No data	0.19 tCO_2e/ha (wheat); 0.15 tCO_2e/ha (maize)	No change	Decrease in production costs $83/ha for wheat and $68/ha for maize	
Alternate Wetting and Drying (AWD)							
AWD, consisting of periodic drying and re-flooding of the rice field	Rice	Bangladesh	No data	0.8 tCO_2e/ha, or 24% decrease, excluding savings from less fuel for pumping	5–13% (0.3–0.7 t/ha)	Decrease in production cost by 4% ($46/ha); older data suggests increase; increase in profit 8–39%	No data, study suggests targeting regions with high energy costs for water pumping, as cost savings are highest there.
		Vietnam	No data	1.8–4.0 tCO_2e/ha (6-39%)	No significant increase	Decrease in production cost by 20% to $538/ha; increase in profit 17–41%	
Sustainable intensification measures							
Inorganic fertilizer use	Maize		US$ 50 additional cost per farm (US$ 500/t)	No data	No data	Increased output of US$ 330 in yields of maize	Liquidity barrier for farmers can be overcome by input financing
Improved soil management	Maize		4% increase in total input costs	No data	No data	15% increase in revenues	Only 5% of adoption rate in districts where it was promoted
Nitrogen fixing trees	Cotton		No data	No data	No data	Benefit to cost ratio 2.77–3.13	Low availability of trees and the lack of nurseries
Integrated pest management	Cotton		US$ 7/ha	No data	No data	Saving of US$ 10/ha in reduced chemical costs; US$45/ha/year additional revenue	Knowledge barrier, lack of supply of traps

Sources: Own elaboration based on: Basak 2016a, Basak 2016b, Gromko et al. 2017

Some leading agribusinesses are increasingly implementing climate change adaptation and mitigation measures in their value chains, largely independently of the international policy discussion. These value chain actors are motivated by consumer demand for sustainably produced commodities. The fact that climate change affects raw material supply from climate-stressed regions forces companies to look for new supply markets and to increase efficiencies. Climate change thereby acts as a development accelerator. The coffee and hazelnut industries e.g. are known to face sourcing challenges due to negative climate change effects on primary production. Water intensive primary producers and processors in horticulture and dairy, have to look into more resource efficient measures in order to cut costs and secure operations in a dryer future. Reducing GHG emissions comes as a side effect of efficiency investments such as energy efficiency or reduced waste.

Mitigation finance mechanisms

In the past few years, several funding sources for climate-smart agriculture have emerged. Mitigation funding is still focused on clean energy (renewable energy and energy efficiency) and has only been able to penetrate the land use sector related to forestry. Mainstream agricultural (development) finance largely does rarely take into account climate mitigation considerations. If funded from climate finance sources, agriculture is mainly covered by adaptation funding and mostly in the form of public sector grants. Both the private sector aspect as well as the mitigation aspect within agricultural climate finance are lacking so far and it remains to be seen how well newly established funds will be able to cover this area.

Public risk mitigation mechanisms available for private investors

Global climate change investments in 2016 reached USD 383bn. Private finance has already overtaken public sources, contributing roughly two-third of global climate finance. Within the public sector, development finance institutions (DFIs) are the largest funder. The majority of finance is raised and spent in the same country and invested in clean energy, mainly in China. Land use investments are only tracked within DFI spending and constitute by far the smallest category there (CPI 2014).

Commercial investors such as banks and profit oriented funds however are typically reluctant to invest in land use mitigation measures due to high project-inherent and borrower risks. Project inherent risks arise from the nature of primary production, where yields are periodical, depend on site conditions and in the case of perennial crops, take years to fully materialize. Unproven technologies represent financial risk and uncertain returns. Long payback periods in often low-margin sectors add to the perceived risk. Borrower risks are related to the type of businesses that are in need of funding for climate-smart agriculture investments. Sophisticated companies with sufficient collateral have access to and are attractive for commercial investors. Small and medium sized agribusinesses typically lack both the financial securities as well as the corporate setup (governance structures, safeguards policies, financial auditing, etc.) to access such financing sources and are perceived as risky clients.

Green Climate Fund (GCF)

The Green Climate Fund (GCF) is the newest of the UNFCCC financial mechanisms and is evolving as the main funding source for both adaptation and mitigation measures across all sectors. Since its creation in 2010 as a result of the 16th COP in Cancun, it has approved 43 projects for a total volume of 7.5 billion USD. Out of the 43 approved projects, 20 are from African countries, 17 from Asia Pacific, eight from Latin America and the Caribbean and three from Eastern Europe. Roughly one third of the projects have a mitigation focus, one third emphasize on adaptation, while one third are cross-cutting across both themes. Private sector programs received slightly over half (53%) of the funding volume so far, public-private partnerships 4% and public initiatives 43% (GCF 2017).

Out of all approved projects with a mitigation focus, only one is in the GCF results area of forests and land use so far: Priming Financial and Land-Use Planning Instruments to Reduce Emissions from Deforestation in Ecuador. It is a 41.2 million USD grant split between the Ministries of Agriculture and Environment of Ecuador, as well as UNEP, UNDP and FAO. UNDP was the accredited national entity who submitted the program for approval to the GCF. The remainder of mitigation projects are in the energy and financial sectors (as of October 2017). As many more proposals for land use based mitigation programs are under development, it remains to be seen how well the GCF will be able to deliver on its commitment to invest into low-emission and climate-resilient development in the agricultural sector.

Global Environment Facility (GEF)

The Global Environment Facility (GEF) was founded in 1991 and includes 183 countries, international institutions, and civil society organizations. As a global public environmental funding institution GEF acts in the areas of biodiversity, climate change, international waters, land degradation, desertification, and others. GEF is entrusted with the financial mechanism of the UNFCCC on policies, program 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.

Info box 11 Enabling private sector investments in Climate-Smart Agriculture and FLR in Latin America

In 2015, the GEF partnered with the Inter-American Development Bank to establish a first of its kind Climate-Smart Agriculture Fund for the Private Sector in Latin America on a pilot basis of US$ 5 million. Climate-smart agriculture investments face a number of hurdles to access finance, including uncertain profitability, lengthy payback periods, as well as significant knowledge barriers regarding sustainable practices. As a result, climate-smart investments may be put off. The fund addresses these barriers by offering risk-tolerant capital with long tenors to catalyze private investment. First-loss guarantees and concessional tranches of resources not available in the commercial market can transform projects into sustainable business investments. Associated technical assistance, now channeled through the IIC13, enable businesses to conduct cost-benefit and feasibility analyses necessary for an investment decision. (IDB 2015)

As a follow up to the Climate-Smart Agriculture Fund, the GEF-IDB Risk Mitigation Instrument for Land Restoration was initiated as a response to the Latin American 20x20 Initiative to restore 20 million hectares of land (see also Chapter 4.2). Investments here will focus on restoration of degraded lands through reforestation and other measures to increase productivity and profitability and enhance carbon stocks. The project has been approved for implementation by the GEF but concrete investments have not materialized yet (GEF 2017).

[13] Inter-American Investment Corporation, the private sector lending arm of the IDB

Climate Investment Funds (CIF)

The Climate Investment Funds (CIF) are currently being phased out since their additionality was questioned by donor countries and funding is shifting towards the GCF. Funds were exclusively channeled through Multilateral Development Banks. Out of its four funding mechanisms, the Pilot Programme for Climate Resilience (PPCR) proved to be most relevant to the agricultural sector, but excluded mitigation activities, unless they were paired with adaptation measures in a climate-smart approach.[14]

4.3 Monitoring, Reporting and Verification of climate mitigation benefits (MRV)

There are a range of applications for agricultural mitigation including projects, but also large landscape-scale projects, national initiatives such as the Nationally Appropriate Mitigation Actions (NAMAs) on Resource Efficiency for Brazil's Beef Supply Chain, and supply chain projects in which agribusiness companies aim to reduce their climate footprint. Across all of these applications, there is a need for robust and credible monitoring, reporting and verification (MRV) capabilities to demonstrate that shifts in agricultural practices produce real changes in net GHG emissions. In many cases, agricultural GHG MRV will be called upon to use a landscape-scale approach in which management decisions and incentive systems can recognize the mosaic of land use types (including forested land) and incorporate the full set of impacts within agricultural landscapes.

The UNFCCC formulates specific requirements for national performance and benefit measuring systems for climate mitigation actions. The Convention specifically mandates the application of the IPCC Good Practice Guidelines to measure and report agricultural emissions at the national level. However, although there is relatively strong consensus on agricultural GHG accounting frameworks, measurement of agricultural mitigation actions is hampered by inherent variability in agricultural emissions and removals and, in many countries, by a lack of available data and limited capacities for measurement. To track these GHG reductions, the IPCC's Guidelines for terminology and approach is the international standard:

1. Relevance: Use data, methods, criteria, and assumptions that are appropriate for the intended use of reported information.
2. Completeness: Consider all relevant information that may affect the accounting and quantification of GHG reductions and complete all requirements.
3. Consistency: Use data, methods, criteria, and assumptions that allow meaningful and valid comparisons.
4. Transparency: Provide clear and sufficient information for reviewers to assess the credibility and reliability of GHG reduction claims.
5. Accuracy: Reduce uncertainties as much as is practical.
6. Conservativeness: Use conservative assumptions, values, and procedures when uncertainty is high.

More scrutiny is evolving at the climate policy level. The newly established Enhanced Transparency Framework outlined in the Paris Agreement aims to provide clarity on support provided and received by relevant individual parties in the context of climate change actions, and, to the extent possible, to provide a full overview of aggregate financial support provided to inform a global stock take (UNFCCC 2017). While differences in national capacities are acknowledged, it is stated that developing countries should provide information on financial, technology transfer and capacity-building support needed and received.

[14] Example projects can be found here: https://www.climateinvestmentfunds.org/fund/pilot-program-climate-resilience

Info box 12 Agricultural MRV+ – A climate benefit monitoring concept for the agricultural sector in Kenya

The main objective under the Kenya Climate Change Action Plan (KCCAP) was to develop a National Performance and Benefit Measurement Framework. The framework integrates monitoring, evaluating and reporting results of mitigation actions, adaptation actions and the synergies and trade-offs between them. A system has been designed that will be embedded in a wider framework and will incorporate Measurement, Reporting and Verification (MRV) of greenhouse gas (GHG) emissions and mitigation activities and Monitoring and Evaluation (M&E) of the adaptation activities. Since the system combines adaptation and mitigation functions, it is referred to as the MRV+ system.

The MRV+ system will assist Kenya by:

- Acting as a guide for the Kenyan Government for the implementation of concrete climate change response actions (adaptation and mitigation).
- Helping Kenya fulfil its international reporting obligations by developing a GHG inventory and tracking mitigation and adaptation actions ready to report to the United Nations Framework Convention on Climate Change (UNFCCC) via National Communications and Biennial Update Reports.
- Demonstrating Kenya's climate finance readiness and providing a strong platform for attracting international climate finance flows from multilateral and bilateral development partners.
- The MRV+ system will carry out a process that contains three main stages as follows:
- Measurement (and Monitoring): First of all data and information needs to be gathered and fed into the system, the data and information needs quality checking and then the evaluation of the data can be carried out.
- Verification: The analysis will produce results that will need to be cross-checked and verified in some way to ensure that they are a realistic estimate of the outcomes being monitored.
- Reporting: Once the results have been verified they can then be reported in whatever format is required.

The concept for a combined agricultural climate benefit MRV system for both adaptation and mitigation (Agri MRV+) is consistent with relevant reporting guidelines of the Intergovernmental Panel on Climate Change (IPCC) as outlined in their Good Practice Guidelines[15]. The overall objectives of this Agri MRV+ design are stipulated into the following principles:

- **The system is based on existing institutional structures that provide accountability in ways appropriate to the national context:** There is a national agricultural monitoring and evaluation system used by different agricultural departments. The current reality is that standards for data collection and processing, agreed frequencies and data aggregation procedures exist in theory but not in practice. The overall approach of the system is to aggregate data from a sample of households at location level and then subsequently to county, ward and headquarters. The design of the proposed Agri MRV+ system will use the existing M&E institutional set-up.
- **Bottom-up approach:** The proposed Agri MRV+ system uses a bottom-up approach where household monitoring data are used to draw conclusions regarding the adaptation and mitigation performance at different administrative levels. On the other hand, this system can be easily integrated into a national accounting system. The advantages of a bottom-up approach, in particular in diverse smallholder conditions, are:

15 http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

- Disaggregation to smaller landscape units, which facilitates linking this system to specific adaption and/ or mitigation projects, initiatives and programs providing local data for a specific region.

- Data provision on the primary producers of agricultural commodities. This is of particular importance for maximizing the efficiency and adaptive capacity of agricultural production along entire value chains.

- The provision of a realistic analysis of adaptation performance of those affected most by climate change. The monitoring data collected from different households provides the opportunity to analyze adaptation in relation to other circumstances (e.g. economic, biophysical, etc.). This could lead to more specific adaptation strategies for different regions and settings in Kenya.

- **Activity-based approach:** The proposed Agri MRV+ system is conceptualized in a way that agriculture- and farm-based activities are assessed and used as proxy indicators for the performance of adaptation and mitigation activities. This is different to other systems where direct measurements of physical parameters, e.g. soil and nutrient status, are used to monitor performance. The Agri MRV+ system is designed to achieve multiple benefits. Above all, the system is transparent for the farmers/pastoralists who are actively involved in any adaptation/ mitigation activities. Furthermore, it provides mutual benefits for any ongoing or future program/ project implementation, extension and impact monitoring. This includes identifying specific training needs and priority interventions for extension. Activity monitoring engages the farmer, provides crucial information to improve extension and self-learning structures and creates an environment of committing the farmers to the relevant adaptation or mitigation activities.

- **The quantified climate benefits are real:** Any performance of climate change adaption or mitigation activities monitored with the system should represent the actual situation on the ground (e.g. actual emission reductions) and not simply be artefacts of incomplete or inaccurate monitoring.

- **The performance of climate smart activities are accurately quantified with known uncertainties:** The proposed Agri MRV+ system uses a sampling approach to collect relevant parameters at farm/ household level. For each parameter the precision and accuracy[16] can be defined, therefore the uncertainty of a specific adaptation or mitigation activity can be quantified.

- **The system includes provisions for quality control and quality assurance:** The system sets clear standards to ensure integrity. All required procedures of the system (data recording, survey activities, data processing, analysis, and data archiving and reporting) are encoded in explicit rules that are transparently communicated, taught and verified.

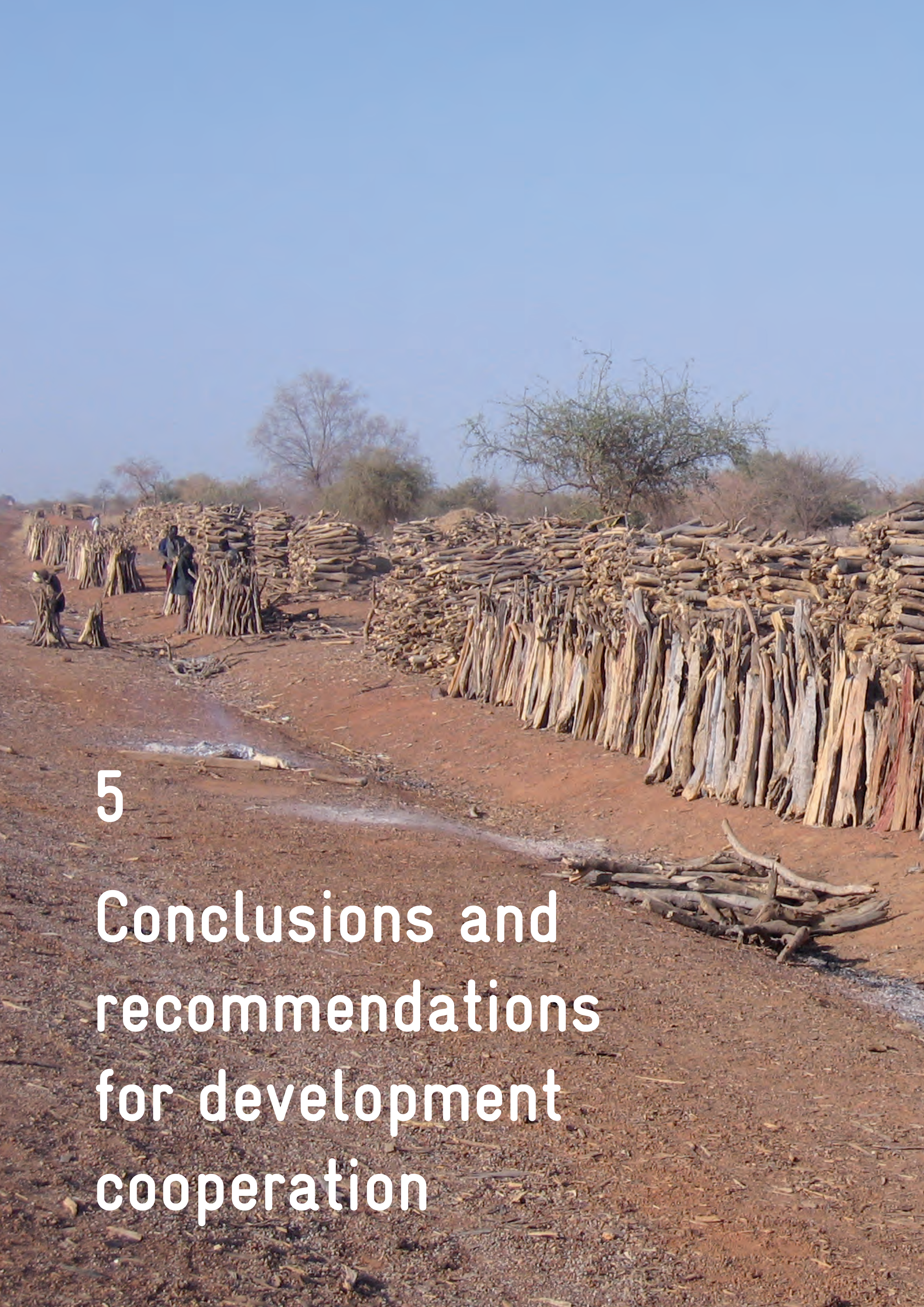
- **Cost effective Agri MRV+ design:** Above all, monitoring the performance of adaptation and mitigation activities needs to be cost efficient. This is achieved by:

  - linking this system to existing national M&E institutional structures, and using many parameters which are already monitored regularly in the country;

  - using existing available data sets from global, regional, or national sources (FAO, KARI, ILRI; ICRAF; etc.). These data are needed to establish a relationship between the activity-based farm data and other important conditions (e.g. climate, soil conditions, etc.); and

  - developing easy-to-use web-based analysis tools for assessing the climate benefits and performance. Once the database is operational, the performance will be automatically analysed based on the input of periodic monitoring data.

[16] Accuracy is how close estimates are to the true value; accurate measurements lack bias and systematic error. Precision is the level of agreement between repeated measurement; precise measurements have lower random error



5

Conclusions and recommendations for development cooperation

A number of lessons of this review may be specifically helpful for international development cooperation.

- Feeding a growing more and more urbanized world population is a challenge for the agricultural sector. Doing so with less overall net agricultural emissions will most probably be impossible. Nevertheless, the potentials for efficiency improvements are huge at various stages of the global agricultural value chains. Area, input and energy efficiency as well as reduced food loss and waste allow less emissions intensity per unit of end product, despite higher emissions from the entire system. Efficiency accounting will be part of the solution in promoting mitigation in agriculture.

- Mitigation in agriculture cannot be seen by itself, because interlinkages to other land use sectors like forestry and water, but also transport and energy are numerous and complex. The concept of landscape restoration encompasses a holistic approach and has the potential to bring the different relevant stakeholders together. Accordingly, capacity development and concrete implementation on the ground need to be embedded in agricultural development programs such as sustainable land management and value chain programs.

- Keeping agriculture out of non-agricultural land, conserving wetlands and productive agricultural soils has the main mitigation potential in the agricultural sector and is more cost-efficient than restoring degraded lands. Sustainable intensification on existing agricultural land and application of good practices are therefore important measures to avoid further degradation. A trigger to scale up such practices lies in the strengthening of capacities of agricultural education, training and extension services.

- Emerging economies such as China, Brazil, India and Indonesia are more essential than least developed countries in terms of agricultural mitigation potential and strategies should be tailored to specific country circumstances. In many emerging economies impoverished smallholder farmer, with an average age above 50 years, still dominate agricultural production systems, while the affluent urban population is rapidly expanding and suffering from the health consequences of unsustainable consumption patterns. Smallholder farmers require support to specialize on crops that generate higher returns, farm mechanization and to form bigger land holdings. At the same time, the affluent urban community requires support to educate the young generation on healthy diets and a better understanding of the environmental consequences of certain forms of food production to increase the demand e.g. for organic food production.

- The private sector is a logical partner in agricultural mitigation due to topics such as deforestation free value chains, efficiency investments in processing as well as sustainable sourcing from farms “upstream” in their value chains. These private actors have a different set of expertise and a network of producers and suppliers that can complement target groups of development cooperation programs and vice versa.

- So far, there are no overarching studies on the economic benefits of mitigation practices by region, commodity and typical farm size. Anecdotal information exists on selected production systems but more in-depth information is needed in order to prove the business case of mitigation measures at farm level in site-specific contexts.

- Demand side measures have not been part of the agricultural mitigation discussion so far, although they represent a large mitigation potential. Measures targeted at consumers in industrialized countries as well as affluent populations in emerging economies and developing countries are often seen as politically sensitive. Reducing food loss and waste is therefore a promising entry point in mitigation. It requires strong alignment of food related trade and retail regulations with private sector action. Due to efficiency gains, there might be a promising business case for companies to invest in such measures.

Literature cited

Alexandratos, N., Bruinsma, J. 2012. World agriculture towards 2030/2050. The 2012 revision. ESA Working Paper No. 12-03. FAO. http://www.fao.org/docrep/016/ap106e/ap106e.pdf

Ausubel , J., Wernick, I., Waggoner, P. 2013. Peak Farmland and the Prospect for Land Sparing. Population and Development Review Volume 38, Issue s1, 221-243.

Barona, E., Ramankutty, N., Hyman, G. and O. Coomes (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon. Environmental Research Letters 5: 024002.

Basak R. 2016a. Benefits and costs of nitrogen fertilizer management for climate change mitigation: Focus on India and Mexico. CCAFS Working Paper no. 161. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Basak R. 2016b. Benefits and costs of climate change mitigation technologies in paddy rice: Focus on Bangladesh and Vietnam. CCAFS Working Paper no. 160. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Beddington J, Asaduzzaman M, Clark M, Fernández A, Guillou M, Jahn M, Erda L, Mamo T, Van Bo N, Nobre CA, Scholes R, Sharma R, Wakhungu J. 2012. Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org/commission.

Bellarby, J., Foereid, B., Hastings, A., and Smith, P. University of Aberdeen 2008. Cool Farming: Climate impacts of agriculture and mitigation potential, Greenpeace, Amsterdam.

Bodirsky B L, Alexander P, Isabelle W, Jan P D, Susanne R, Lena S, Christoph S and Hermann L-C 2012. N_2O emissions from the global agricultural nitrogen cycle – current state and future scenarios. Biogeosciences 9 4169–97.

Bodirsky, B. & Müller, C. 2014. Robust relationship between yields and nitrogen inputs indicates three ways to reduce nitrogen pollution. Environ. Res. Lett. 9 111005.

Bouwman, L., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H.W., Van Vuuren, D. P., Willems, J., Rufino, M.C. and E. Stehfest 2011. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. Proceedings of the National Academy of Sciences 110: 20882 – 20887.

Braun, A., Van Dijk, S. & Grulke, M. 2016: Upscaling silvopastoral systems in South America. IDB-IIC Monograph.

Brentrup, F. and Pallière, C. 2008. International Fertilizer Society Proceedings 639.

CGIAR 2017. Global Rice Science Partnerships. Ricepedia, The online authority on rice. Accessed online October 2017 under http://ricepedia.org/rice-as-food/the-global-staple-rice-consumers.

Climate Focus 2017. Progress on the New York Declaration on Forests: Finance for Forests - Goals 8 and 9 Assessment Report. Prepared by Climate Focus in cooperation with the New York Declaration on Forest Assessment Partners with support from the Climate and Land Use Alliance.

Climate Focus 2016. Progress on the New York Declaration on Forests – Achieving Collective Forest Goals. Updates on Goals 1-10. Prepared by Climate Focus in cooperation with the

NYDF Assessment. Coalition with support from the Climate and Land Use Alliance and the Tropical Forest Alliance 2020.

Haupt, F., Streck, C., Bakhtary, H., Galt, H., 2017. Taking a Bite Out of Climate Change: Why We Should Stop Harming the Planet and Ourselves by Eating Too Much Beef . Working Paper prepared by Climate Focus.

CPI 2018. Global Landscape of Climate Finance. http://www.climatefinancelandscape.org

Johannes Dill, J., Deichert, G., Le Thi Nguyet Thu 2013. Promoting the System of Rice Intensification. Lessons Learned from Trà Vinh Province, Viet Nam. GIZ, Germany.

Doss C. 2011. If women hold up half the sky, how much of the world's food do they produce? ESA Working Paper No. 11–04. Rome: FAO.

EPA 2017. Water – energy connection. Website accessed October 2017 under https://www3.epa.gov/region9/waterinfrastructure/waterenergy.html.

Tubiello, F.N., M. Salvatore, R.D. Cóndor Golec, A. Ferrara, S. Rossi, R. Biancalani, S. Federici, H. Jacobs, A. Flammini 2014. Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks. 1990 – 2011 Analysis. FAO Statistics Division Working Paper Series ESS/14-02. Accessed online November 2017 under http://www.fao.org/docrep/019/i3671e/i3671e.pdf.

FAO, 2009. Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. FAO, Rome. (http://www.fao.org/docrep/012/i1318e/i1318e00.pdf).

FAO 2010. Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome, FAO. http://www.fao.org/docrep/013/i1881e/i1881e00.pdf

FAO 2011. The state of food and agriculture. Women in agriculture. FAO, Rome, Italy.

FAO 2011a. Mapping supply and demand for animal-source foods to 2030, by T.P. Robinson & F. Pozzi. Animal Production and Health Working Paper No. 2. FAO, Rome, Italy.

FAO 2011b. Global food losses and food waste – Extent, causes and prevention. Rome, Italy.

FAO 2014. Agriculture forestry and other land use emissions by sources and removals by sinks. Rome, Italy.

FAO 2015. Technical Platform on the Measurement and Reduction of Food Loss and Waste. http://www.fao.org/platform-food-loss-waste/food-waste/food-waste-reduction/country-level-guidance/en.

FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR). Rome (Italy): Food and Agriculture Organization of the United Nations und Intergovernmental Technical Panel on Soils.

FAO 2016a. Greenhouse gas emissions from Agriculture, Forestry and Other Land Use. Accessed online October 2017 under http://www.fao.org/3/a-i6340e.pdf.

FAO 2016b. Global Forest Resources Assessment 2015. How are the world's forests changing? Second edition. Rome, Italy.

FAO 2017. Rice and climate change. Accessed online October 2017 under http://www.fao.org/fileadmin/templates/agphome/documents/Rice/rice_fact_sheet.pdf.

FAO 2017b. Food Wastage Footprint and Climate Change. Available online at http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/FWF_and_climate_change.pdf.

FAO 2017c. The future of food and agriculture – Trends and challenges. Rome. Available online at http://www.fao.org/3/a-i6583e.pdf.

FAOSTAT (without year). Food and agriculture data by FAO. Available online under http://www.fao.org/faostat/en/#home.

Fearnside P.M. 2005. Deforestation in Brazilian Amazonia: history, rates and consequences. Conservation Biology 19: 680 – 688.

Federal Democratic Republic of Ethiopia 2011. Ethiopia's Climate-Resilient Green Economy. Green economy strategy.

Food Matters 2016. Environment Reports of the Institute on the Environment, University of Minnesota. Accessed online November 2017 under http://www.environmentreports.com/how-does-agriculture-change/#section2.

Frank, S., Petr Havlík, Jean-François Soussana, Antoine Levesque, Hugo Valin, Eva Wollenberg, Ulrich Kleinwechter, Oliver Fricko, Mykola Gusti, Mario Herrero, Pete Smith, Tomoko Hasegawa, Florian Kraxner and Michael Obersteiner 2017. Reducing greenhouse gas emissions in agriculture without compromising food security? Environ. Res. Lett. 12 105004. GEF 2017. Risk Mitigation Instrument for Land Restoration (Non-Grant). GEF online project repository, accessed October 2017 under https://www.thegef.org/project/risk-mitigation-instrument-land-restoration-non-grant.

Gerber, P.J., Hristov, A.N., Henderson, B., Makkar, H., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A.T., Yang, W.Z., Tricarico, J.M., Kebreab, E., Waghorn, G., Dijkstra, J. & Oosting, S. 2013. Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review. Animal, 7 (2): 220–234.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and G. Tempio 2013a. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome. Italy.

Gerssen-Gondelach, S.J., Lauwerijssen, R.B.G., Havlik, P., Herrero, M., Valin, H., Faaij, A.P.C. and B. Wicke 2017. Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change. Agriculture, ecosystems and environment 240: 135 – 147.

Gibbs, H. K., Salmon, J.M. 2015. Mapping the world's degraded lands. *Applied Geography* 57 (February): 12–21. doi:10.1016/j.apgeog.2014.11.024.

Global Panel on Agriculture and Food Systems for Nutrition 2016. Food systems and diets: Facing the challenges of the 21st century. London, UK.

Green Climate Fund (GCF) 2017. Green Climate Fund website. Accessed October 2017 under http://www.greenclimate.fund.

Green Climate Fund (GCF) 2017. Mainstreaming gender in Green Climate Fund Projects. A practical manual to support the integration of gender equality in climate change interventions and climate finance.

Gromko, D., Kadgi, P., Pistorius, T., Tennigkeit, T., Bertenbreiter, W. 2017. Toward zero deforestation cotton in Zambia. In: ETFRN (2017) Zero deforestation: A commitment to change. ETFRN News no. 58, June 2017. Tropenbos International, Wageningen, the Netherlands.

Heinrich Böll Foundation 2014. Meat Atlas. Facts and figures about the animals we eat. Berlin, Germany.

Herrero, M., Thornton, P.K., Gerber, P. and R.S. Reid 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Current opinion in environmental sustainability 1: 111 – 120.HLPE 2017. Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome, Italy.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R.S., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn E. 2012. An assessment of deforestation and forest degradation drivers in develop-ing countries. Envi-ronmental Research Letters, 7(4): 0044009, 12.

Hristov, A.N., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A., Yang, W., Tricarico, J., Kebreab, E., Waghorn, G., Dijkstra, J. & Oosting, S. 2013. Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO_2 emissions. Edited by Pierre J. Gerber, Benjamin Henderson and Harinder P.S. Makkar. FAO Animal Production and Health Paper No. 177. FAO, Rome, Italy.

IFA 2017. Assessment of Fertilizer Use by Crop at the Global Level. International Fertilizer Association (IFA) and International Plant Nutrition Institute (IPNI).

IFPRI 2017. Global food policy report. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/cdmref/p15738coll2/id/131085/filename/131296.pdf.

Inter-American Development Bank (IDB) 2015. IDB approves climate-smart agriculture fund. Press release accessed October 2017 under http://www.iadb.org/en/news/news-releases/2015-07-16/climate-smart-agriculture-fund,11207.html.

IPCC 2014. Climate Change 2014: Mitigation of Climate Change. Cambridge, UK and New York, USA.

IUCN & WRI 2017. A world of opportunity. The world's forests from a restoration perspective. The Global Partnership on Forest Landscape Restoration. Available online under https://www.profor.info/sites/profor.info/files/Landscapes-Opportunity21Jan11_0.pdf.

Kahrl F, Li Y, Su Y, Tennigkeit T, Wilkes A and J Xu. 2010. Greenhouse gas emissions from nitrogen fertilizer use in China. Environmental Science & Policy 13(8): 688-694

Kissinger, G., M. Herold, V. De Sy. (2012) Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers. Lexeme Consulting, Vancouver Canada

Köhl, M., Rodel Lasco, Miguel Cifuentes, Örjan Jonsson, Kari T. Korhonen, Philip Mundhenk, Jose de Jesus Navar, Graham Stinson, Changes in forest production, biomass and carbon: Results from the 2015 UN FAO Global Forest Resource Assessment, In Forest Ecology and Management, Volume 352, 2015, Pages 21-34, ISSN 0378-1127, https://doi.org/10.1016/j.foreco.2015.05.036.Lal, R. 2015. Soil Carbon Pool as an Environmental Indicator. Carbon Management and Sequestration Center. The Ohio State University.

Lampayan, R., Rejesus, R., Singleton, G., Bouman, B. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. Field Crops Research 170 (2015) 95–108.

Lassaletta L, Billen G, Grizzetti B, Anglade J and Garnier J 2014. 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland Environ. Res. Lett. 9.

Mekkonen, M. and A. Hoekstra 2012. A global assessment of the water footprint of farm animal products. Ecosystems 15(3): 401 – 415.

Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T., Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, X. Zhang, 2007: Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nash, J., Peña, O., Galford, G., Gurwick, N., Pirolli, G., White, J., Wollenberg, E. 2017. Reducing food loss in agricultural development projects through value chain efficiency. CCAFS Working Paper no. 204.

Nepstad D.C., Stickler C.M. and O.T. Almeida (2006). Globalization of the Amazon soy and beef industries: opportunites for conservation. Conservation Biology 20: 1595 – 1603.

Nguyen et al. 2008

Ortiz, O., Villamizar, R., Naranjo, C., Garcia, R., Castaneda, M. 2016. Carbon footprint of the Colombian cocoa production. Journal of the Brazilian Association of Agricultural Engineering.

Oenema, O., Xiaotang, J., de Klein, C., Alfaro, M., del Prado, A., Lesschen, J., Zheng, X., Velthof, G., Ma, L., Gao, B., Kroeze, C., Sutton, M. 2014. Reducing nitrous oxide emissions from the global food system. Current Opinion in Environmental Sustainability, volumes 9-10, 55-64.

Paustian, K. et al. 2016: Climate-smart soils. Nature 532.

Popp A, Lotze-Campen H and Bodirsky B (2010). Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production, Global Environmental Change 20, 451–462.

Price, J., Littleton, E., Le Quéré, C. 2016. Greenhouse gas emissions from Agriculture, Forestry and Other Land Use (AFOLU). AVOID 2 programme (DECC). Accessed online November 2017 under http://avoid-net-uk.cc.ic.ac.uk/wp-content/uploads/delightful-downloads/2016/04/Greenhouse-gas-emissions-from-AFOLU-AVOID2-E1.pdf.

Reid, C.S., Galvin, K.A., Kruska, R.L. 2008. Global significance of extensive grazing lands and pastoral societies: an introduction. In Fragmentation in Semi-Arid and Arid landscapes: Consequences for Human and Natural Systems. Edited by K.A. Galvin. Springer, 2008: 1 -14.

Ripple, W., Smith, P., Haberl, H., Montzka, S., McAlpine, C., Boucher, D. 2014. Ruminants, climate change and climate policy. Nature Climate Change 2014.

Ritchie, H., Roser, M. 2017. Meat and Seafood Production & Consumption'. Retrieved from: https://ourworldindata.org/meat-and-seafood-production-consumption [Online Resource].

Rivera, J., Chará, J., Murgueitio, E., Molina, I., Barahona, R. 2016: Greenhouse gas emissions and carbon sequestration potential in conventional pastures and intensive silvopastoral systems under tropical conditions. Conference paper.

Roberts, T.L. 2009. The role of fertilizer in growing the world's food. Better crops, Vol 93, 2.

Scherr, S.J., Shames, S. & Friedman, R. (2012). From climate-smart agriculture to climate-smart landscapes. Agric. Food Secur., 1, 12. Smith P. 2012. Agricultural greenhouse gas mitigation potential globally, in Europe and in the UK: what have we learnt in the last 20 years? Global Change Biology 18, 35 – 43. doi: 10.1111 / j.1365 - 2486.2011.02517.x, ISSN: 1365-2486.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, 2007. Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United King-dom and New York, NY, USA.

Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N.H. Ravindranath, C.W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, Tubiello, F. 2014. Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel V., Rosales M. and C. de Haan 2006. Livestock's long shadow: environmental issues and options. FAO, Rome, Italy.

Tubiello, F., Salvatore, M., Cóndor Golec, R., Ferrara, A., Rossi, S., Biancalani, R., Federici, S., Jacobs, H., Flammini, A. 2014. Agriculture, forestry and other land use emissions by sources and removals by sinks. FAO, Rome, Italy.

UNDP 2012. Global Gender Climate Alliance 2012. Overview of linkages between gender and climate change. Policy Brief.

UNFCCC 2017. Transparency of support under the Paris Agreement. Website accessed October 2017 under http://unfccc.int/cooperation_and_support/financial_mechanism/items/10121.php.

US-EPA 2006. Global mitigation of non-Co2 greenhouse gases. Washington DC, United States Environmental Protection Agency (No. 430-R-06-005).

Vermeulen, S., Campbell, B., Ingram, J. 2012. Climate change and food systems. Annual Review of Environment and Resources Vol. 37:195-222.

Vietnam Forests and Deltas Program 2017. Climate-smart rice supports livelihoods and the environment. A Vietnam Forests and Deltas Program (VFD) Success Story.

Wilkes A, van Dijk S. 2017. Gender Issues in Biogas Promotion and Use in Kenya: A preliminary review. CCAFS Working Paper No. 201. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Wilkes, A. and Tennigkeit, T. 2010. Carbon finance in extensively managed rangelands: issues in project, programmatic and sectoral approaches. Grassland carbon sequestration: management, policy and economics. FAO, Rome. http://www.fao.org/docrep/013/i1880e/i1880e00.pdf.

Wood, S. & Cowie, A. 2004. A Review of Greenhouse Gas Emission Factors for Fertiliser Production. Research and Development Division, State Forests of New South Wales. Cooperative Research Centre for Greenhouse Accounting.

WRI 2017. The Global Restoration Initiative. Accessed online October 2017 under http://www.wri.org/our-work/project/global-restoration-initiative.

Zeleke, Alemayehu & Phung, Thuy & Tulyasuwan, Natcha & O'Sullivan, Robert & Lawry, S. 2016. Role of Agriculture, Forestry and Other Land Use Mitigation in INDCs and National Policy in Asia. . 10.13140/RG.2.1.1899.6086.

Zomer, R., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., van Noordwijk, M. & Wang, M. 2016: Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. Scientific Reports 6, Article number: 29987.

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn, Germany

Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de

On behalf of

Federal Ministry
for Economic Cooperation
and Development