STRATEGIES FOR

Mitigating Climate Change in Agriculture

Abridged Report

April 2014

CLIMATEFOCUS

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Strategies for Mitigating Climate Change in Agriculture:

Abridged Report

This is an abridged version of "Strategies for Mitigating Climate Change in Agriculture: Recommendations for Philanthropy." The full report includes recommendations for interventions and a technical annex.

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WEB PLATFORM:

www.agriculturalmitigation.org contains a copy of this abridged report, the full report, the executive summary, the technical annex as well as various supplementary materials including:

Background analyses of the global agricultural sector

- Finance
- Institutions
- Mitigation practices
- Sources of emissions
- Trade

Agricultural sector and policy profiles for specific countries / regions:

- Brazil
- China
- European Union
- India
- United States

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CONTENTS

EXECUTIVE SUMMARY

Agriculture contributes substantially to global climate change. The sector accounts for roughly a fifth of greenhouse gas (GHG) emissions when one considers the full life cycle of production including agriculture's role in deforestation. This is a massive number, comparable in scale to the transportation sector. Further, this ratio can be even higher in developing countries where the agriculture and forestry sectors together often account for a majority of total emissions. Yet, historically, climate negotiators and policy makers have paid relatively little attention to the agricultural sector in the global effort to slow climate change.

A constructive debate on agriculture and climate change is hampered by a false dichotomy between food security and environmental health. Civil society often approaches agriculture with an overarching mission of *either* improving food security and strengthening smallholder livelihoods *or* reducing the environmental degradation caused by agricultural systems. The option of supporting productive, low-emissions agricultural systems often falls through the cracks of these agendas. There is also little discussion about the opportunities provided by reducing emissions through shifting diets as well as the reduction of food loss and waste. The specter of mitigation practices that risk reducing yields may be preventing a useful integration of the food security and livelihoods agenda with that of the climate and environmental community. Given the likely impacts of climate change on poor and vulnerable communities, we cannot afford to approach agriculture from these silos any longer.

In recent years there have been a number of developments which indicate a positive shift towards incorporating climate into a broader agricultural agenda. Examples include the creation of the Global Research Alliance on Agricultural Greenhouse Gases; the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS); the support of Climate Smart Agriculture by international organizations (World Bank, FAO); Brazil's Low Carbon Agriculture program (Agricultura de Baixa Emissão de Carbono, ABC); and Animal Change (a European Commission funded research effort).

Yet, still more resources need to be brought to bear on the intersection of agriculture and climate change, particularly as there are multiple, complex challenges in addressing this nexus. Production is exceedingly diffuse, the demand for carbon intensive meat is increasing, there are research needs and challenges to mitigating agricultural emissions, and there are very high levels of uncertainty associated with the mitigation potential of various interventions. While it will be a persistent challenge, we have the resources needed to create agricultural systems that are more productive and less GHG intensive. Moving quickly towards higher productivity, lower emissions agricultural systems is in the long-term interest of stakeholders throughout the agricultural sector, including national governments, agribusinesses, multi- and bi-lateral financial institutions, and most importantly, farmers.

Summary of Strategies

This report was commissioned to identify GHG mitigation options in the agricultural sector. Our analysis provides a snapshot of the global mitigation potential in the year 2030, compared to a hypothetical baseline in which no additional mitigation from agriculture is attempted, beyond current adoption and intensification trends. Our recommendations focus on GHG mitigation options while also supporting the food security and climate resiliency needs. We concentrate on mitigation options that reduce the GHG intensity of agriculture, both by changing production practices without harming yields and by shifting demand to lower-GHG intensive products. At its heart, this report has four overarching recommendations:

1. **Shift consumption patterns.** We will be unable to reverse growing agricultural emissions trends unless we address their root cause: rising demand for agricultural products, particularly those that are carbon intensive. Agricultural GHG emissions cannot be addressed simply as a problem of inefficient production on the supply-side. A spotlight must be cast on the pressures that inefficient, unsustainable consumption patterns pose to global climate and land use. This report estimates that nearly 3 gigatonnes of carbon dioxide equivalents (Gt CO_2e) per year could be mitigated through changes in diets and reductions in food waste in 2030 compared with a business as usual scenario. About 75 percent of this mitigation potential comes from changes in diet and the other 25 percent from reductions in food loss and waste. These major shifts in demand for agricultural products represent an emissions reduction of roughly 55 percent of direct agricultural emissions in 2030.

   It is important to address rising meat consumption, particularly beef. Beef cattle represent 35 percent of direct agricultural emissions; dairy cattle and meat and dairy from other ruminants add another 28 percent. Per unit of protein, or per calorie, beef and other ruminants are extremely carbon intensive sources of food, even without considering cattle's role in driving deforestation. If global populations adopt U.S. consumption patterns, the associated emissions would be enormous. Interventions that can help curtail major increases in beef consumption both in industrialized countries and in emerging economies will be critical over the next few decades. Given the established links between diet-related diseases and high levels of meat consumption, keeping global average per capita meat consumption at reasonable levels will have important health benefits as well.

   In addition to dietary choice, several other interventions have promise including reducing the egregious levels of food waste and loss around the world and curtailing the use of food crops for biofuels. A range of actions including policy changes, behavioral change, and infrastructure investments can help address these issues.

2. **Focus on key agricultural producers that can achieve major productivity gains.** Demand-side interventions need to be paired with efforts to improve the efficiency of production. One of the largest challenges in containing the growth of agricultural GHG emissions is the diffuse nature of production. While there are countless mechanisms that could reduce GHG emissions, there are only a limited number of countries and sectors that can yield meaningful reductions (i.e., at least 40 to 50 million tonnes (Mt) CO_2e reductions per year by 2030) with practices that would be beneficial to producers and to yields. In the aggregate, the emissions reduction potential of the agricultural sector through supply-based approaches is nearly 2 Gt CO_2e per year by 2030, including efficiencies gained in fertilizer production in China. These emissions reductions represent about a 30 percent reduction from 2030 levels. Priority focus areas should include:

   - Reducing enteric fermentation emissions from Brazil's cattle population and India's dairy herd. The mitigation opportunities are large, would yield productivity gains, and ought to be in the best interest of the farmers and governments. In each case, the opportunity involves improving the quality of livestock diets so that farmed animals can reach market weight more quickly, and produce more meat and milk. These changes not only result in lower emissions on per unit of product, but also improve the economics and productivity of the herds, and can allow smaller animal populations to support a sustained production level.

   - Increasing the efficiency of nutrient use on China's croplands. China is believed to have the greatest overuse of fertilizer globally. Simple measures can greatly reduce GHG emissions from fertilizer application in China without harming yields. In many cases, reduced fertilizer application would benefit yields and long-term soil fertility. In addition, securing major industrial inefficiencies in China's fertilizer production would yield very significant GHG reductions.

   - Reducing rice emissions in Southeast Asia. Although this opportunity is spread across a region instead of a single country, rice farming has both high emissions and mitigation potential due to the amount of rice grown in flooded fields. Many of the interventions used to reduce rice emissions are complementary with productivity gains, such as adding irrigation to better control water, which allows for double cropping.

- Improving stored manure practices in industrialized livestock systems. While mitigation interventions that target stored manure management do not benefit productivity, they also present no serious food security risks and have other co-benefits (e.g., water quality). Unlike many mitigation options, manure management has been addressed through progressive policies in many countries.

Interventions need to be designed on a case-by-case basis, specific to country-level conditions. Common interventions for encouraging changes in agricultural practices include expanding extension capacity, expanding the availability of subsidized loans, providing financial incentives, and working directly with producer groups.

3. **Pursue catalytic, cross-cutting interventions.** Achieving high productivity, low emissions agriculture across the globe will require that mitigation practices be incorporated into the daily business of actors across the agricultural sector. Agricultural ministries, agribusinesses, and financial institutions and donors, all need to create and adopt best practices for an integrated climate and productivity agenda in agriculture. There are several high leverage opportunities that are already gaining traction and ought to be examined in more detail:

    - Standards and guidelines for low emissions agricultural investments that steer money away from high emissions agricultural activities would be very beneficial. This opportunity may be particularly timely given the World Bank's recent commitment to Climate Smart Agriculture.
    - Greater transparency and accountability in corporate supply chains would strengthen the climate-oriented investments and commitments of major food and agribusinesses.
    - Agricultural trade issues are stymied in both the United Nations Framework Convention on Climate Change (UNFCCC) and World Trade Organisation (WTO) proceedings due to presumed jurisdictional limitations of each intergovernmental body. Targeted analysis might be able to break the gridlock, potentially removing barriers and allowing incentives for agricultural mitigation measures in both the WTO and UNFCCC.
    - Reform of agricultural subsidies in major agricultural economies, particularly the E.U. and U.S., would be enormously valuable. Advocacy around these programs may be worth the effort, even if they are long-term strategies.

4. **Take a rational approach to agricultural carbon sequestration.** Of the many debates on agricultural mitigation, perhaps none has endured as many fluctuations in recent years as the discussion surrounding the role of carbon sequestration in agricultural soils and above-ground biomass. This report estimates a global carbon sequestration potential of between 700 and 1,600 Mt CO_2e per year by 2030. The mitigation, yield and economic impacts of sequestration are not well understood for all practices, and there are complicating factors such as the impermanent nature of carbon stocks. Given these challenges, agricultural carbon sequestration should not be embraced or pursued *in lieu* of other mitigation opportunities.

    However, long-term management and preservation of soil carbon is critical for agricultural productivity because it increases soil fertility, reduces erosion, and increases moisture retention. And sequestering carbon in agricultural systems can be part of the climate solution. Maintaining soil organic matter is vital for farmers and ranchers everywhere, regardless of the potential to measure or monetize sequestration. One way to prioritize support for increased soil carbon sequestration is to identify those geographies where soil carbon content is particularly low and where the links to food security, poverty reduction, and productivity gains are strongest. This report focuses on the croplands of Sub-Saharan Africa and the grazing lands of Brazil as two geographies where carbon sequestration would support broader efforts to improve soil fertility and forage productivity, for the long-term benefit of producers. Additionally, this report recommends continued, long-term investments in research and development of promising new practices, specifically biochar, as well as improved data on soil types, soil carbon contents and fluxes, specifically in Sub-Saharan Africa.

Summary of methodology

This report was designed to address mitigation opportunities in the agricultural sector. The analysis is intended to help readers understand the relative magnitude and feasibility of mitigation opportunities. It draws a tight boundary around the agricultural sector and omits a number of mitigation opportunities connected to agriculture such as: reduced deforestation, restoration of abandoned lands, restoration of peatlands, fossil fuel offsets from bioenergy, emissions fluxes related to land use change driven by increases or decreases in biofuels and bioenergy, and energy and industrial efficiency along the agricultural supply chain (with the exception of fertilizer production in China). Many of these opportunities are worthy of exploration and support.

The quantitative analysis included in this report provides an overview of the technical potential for GHG mitigation in the agricultural sector in the year 2030, compared with a baseline projection, calculated by country and emitting sector. Technical mitigation potential represents the emissions reductions or carbon sequestration possible with current technologies, ignoring economic and political constraints.

We applied a range of approaches to determine the mitigation potential for the main categories of interest: enteric fermentation, manure management, rice management, fertilizer application to crops, carbon sequestration on croplands and grazing lands, and changes in demand. In all cases, we relied on existing published literature and data. Because agricultural emissions and mitigation have such high uncertainty levels, technical mitigation potential can be difficult to estimate precisely; one could reasonably use different data or assumptions than those employed in this report and obtain a divergent estimate of technical mitigation potential.

Building on the technical assessment of mitigation potential, this report identifies priority areas for mitigation based on the feasibility of engagement. For each priority country and commodity, a more in-depth analysis was conducted to determine whether and how the mitigation potential might be achieved. The technical requirements of individual mitigation opportunities are assessed along with various intervention approaches including national and international policies, corporate supply chain engagement, and multilateral financing.

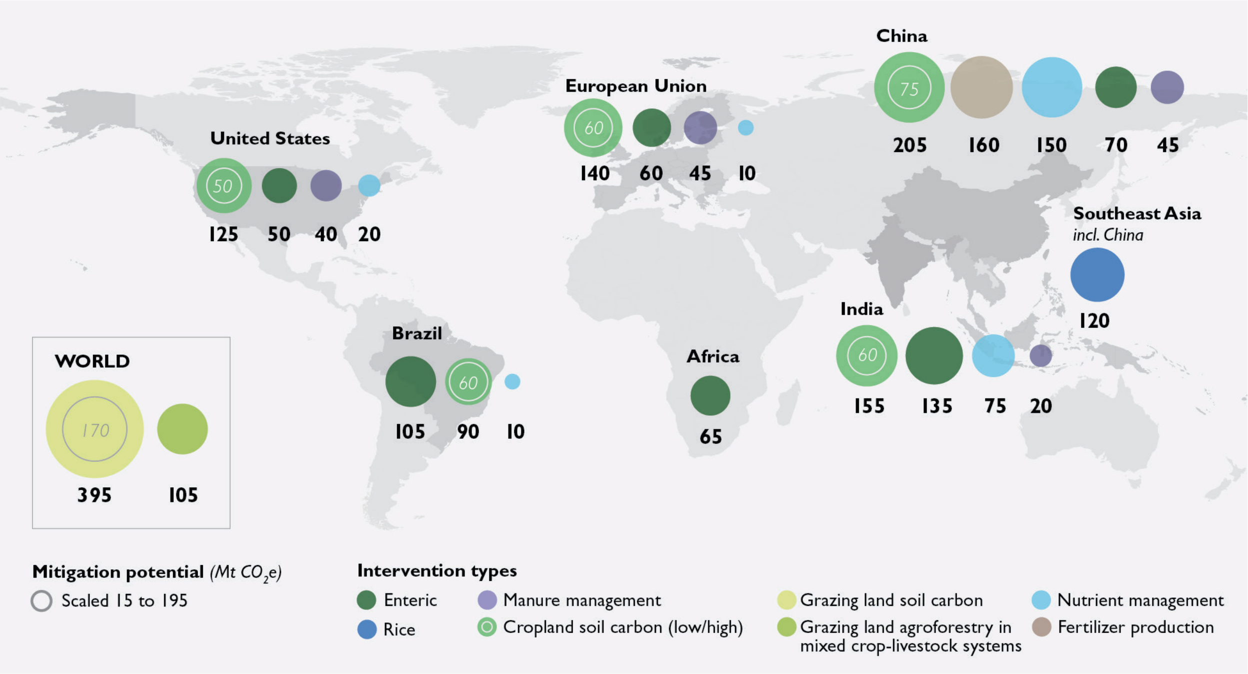
For a full description of the methodology and sources used, please see Annex 3 of the full report.

Summary of priority areas

The pressures on land, natural resources, climate, and people continue to grow. Win-win solutions exist and must be pursued aggressively by all factions that are collectively charting the course for agriculture in the 21st century. The map below shows mitigation potential and priority areas for interventions.

Global mitigation opportunities (technical potential)

For a complete version of this figure, see page 30.



I.

INTRODUCTION

1.1
BACKGROUND AND JUSTIFICATION FOR ACTION

Agriculture lies at the heart of many fundamental global challenges faced by humanity including food security, economic development, environmental degradation, and climate change. There is no humanitarian goal more crucial than feeding a world population projected to expand beyond nine billion by 2050. Meeting increases in food demands associated with growing population and income levels is likely to require increases in total food production of 50 percent or more by mid-century.[1] Furthermore, no other economic sector is more vital to safeguarding human livelihoods. Agriculture provides employment for 2.6 billion people worldwide and accounts for 20 to 60 percent of the gross domestic product of many developing countries, forming the backbone of rural economies, contributing to local employment, and ensuring food security for poorer populations.[2]

With consumption of all natural resource commodities increasing under the pressures of population growth and rising standards of living, there is continuing pressure for agriculture to expand and intensify. While governments, bilateral development agencies, and multilateral financial institutions are dedicating significant resources to increasing agricultural yields globally, less emphasis has been placed on making agriculture environmentally sustainable. Croplands and pasturelands already cover nearly 40 percent of the earth's land area,[3] and agriculture consumes 70 percent of freshwater used by humans, much of which is sourced from non-renewable aquifers.[4] Agriculture is the world's largest driver of species loss and habitat conversion, and is a major contributor to toxic and nutrient pollution, soil degradation, and invasive species introductions. These pressures on our resources will only continue to grow as global population and income levels rise.

The agricultural sector is also a major contributor to GHG emissions. Most studies attribute about twenty to twenty-five percent of all global GHG emissions to the production of food, feed, and biofuels, including emissions from agriculture-driven land use change. Though these numbers are substantial and comparable in aggregate to the transportation sector, agriculture's potential contributions to GHG mitigation have received little attention the international dialogs on climate change mitigation. If agricultural systems are to meet the future needs of an expanding global population, significant progress will need to be made in helping the agricultural sector as a whole—and farmers in particular—increase the resilience of farming systems to climate change, better preserve soil fertility and freshwater flows, and reduce impacts on deforestation, biological diversity, and GHG emissions.

Though this report is focused on mitigation opportunities in the agricultural sector, it identifies opportunities that are in alignment with productivity gains. Because of the primacy of food security, any mitigation effort in the agricultural sector must focus on reducing emissions intensity (i.e., emissions per unit of production), rather than emissions per hectare or aggregate emissions. A focus on reductions in emissions intensity allows for a merging of environmental and humanitarian objectives, as many mitigation opportunities in the agricultural sector are entirely aligned with productivity gains. There is a significant opportunity which has been largely unmet, for investments in agricultural systems to reduce GHG emissions and to increase the overall resilience of the sector in the face of impacts from climate change, while maintaining or increasing production yields. We believe it is not only possible to pursue and better incorporate a mitigation agenda that does not undermine these other priorities, but that doing so is in the best long-term interest of stakeholders throughout the agricultural sector including national governments, agribusinesses, multi- or bi-lateral financial institutions, and most importantly, farmers.

That said, determining where and how GHG emission reductions and carbon sequestration are best achieved will depend on the specific farming systems as well as country and region specific political and economic conditions. While we believe that there is a vast territory of potential gains for both the climate and productivity agendas, mitigation may not always be in the best interest of specific countries or farmers, even in the long term. Therefore, trade-offs between potentially competing goals for the agricultural sector need to be recognized, balanced and managed.

Thought leaders and practitioners across the field are increasingly embracing the concept of "sustainable intensification." However, there are disparate views on what a this concept implies, ranging from low-input, decentralized, smallholder systems to highly intensified, centralized, single-crop systems. Regardless of the scale, or agricultural philosophy, it is clear that agricultural systems must push strongly and consistently towards higher productivity and lower emissions in the coming years and decades.

1.2

OBJECTIVE OF THE REPORT

This report describes the main sources of agricultural emissions, reviews GHG mitigation opportunities in the agricultural sector, and presents guiding recommendations. The report is the result of a study commissioned in 2013 by the Climate and Land Use Alliance (CLUA)—a collaborative initiative of the ClimateWorks Foundation, the David and Lucile Packard Foundation, the Ford Foundation and the Gordon and Betty Moore Foundation—and executed by Climate Focus and California Environmental Associates (CEA).

The scope of the report was tightly drawn around GHG emissions and mitigation opportunities in the agricultural sector. While we recognize that the boundaries between the forestry and agricultural sectors are porous, we have focused our recommendations on achieving emission reductions and removals within the agricultural sector. This report includes the following categories:

- **Direct agricultural emissions reductions.** Opportunities to reduce the emissions associated with on-farm emissions from crop and livestock production, limited to methane and nitrous oxide emissions (i.e., excluding CO_2 emissions from on-farm equipment, which for the purposes of this report are considered "supply chain" emissions).
- **Carbon sequestration within agricultural systems.** Opportunities to increase the amount of carbon stored in cropland soils, grazing land soils, or above-ground biomass (e.g., agroforestry systems).
- **Demand shifts.** Reducing overall agricultural production (e.g., by reducing food waste) or shifting away from high-carbon intensity agricultural products such as meat from ruminants.

These recommendations seek to complement activities in the area of reduced emissions from deforestation and forest degradation (REDD+). We therefore have not developed recommendations for land use change emissions and consider the following areas out of scope:

- **Forest emission reductions and forest carbon sequestration.** Relevant activities, such as the restoration of degraded lands, afforestation and the reduction of emissions from deforestation should be included in any land use related mitigation strategy. However, as they form part of REDD+ and forest carbon strategies, they fall outside of the scope of this report.
- **Reduction of emissions from land use change through the expansion of biofuels.** While the direct emissions from the production of biofuels from agricultural crops are covered by this report, the effect of biofuels on forest conversion and land use change would fall primarily under REDD+

and forest carbon strategies. However, we give an overview on the role of subsidies in the area of biofuels in the Annex of this report. Other forms of bioenergy (e.g., crop residues, manure, forestry residues, and green waste) are also not covered in this report.

- **Reduction of emissions from drained peatlands.** Peatlands cover only 3 percent of the global land area but are the most carbon-dense lands among terrestrial ecosystems. Peatlands that are drained and degraded, typically for agricultural use, emit more than 2 Gt CO_2e annually.[5] Through rewetting of peatlands it is possible to restore carbon levels in peat soils that have already been degraded.[6] However, the restoration of wetlands does not technically fall under agricultural activities, is a specialized discipline with its own experts and discussion fora, and is hence not considered.

This study complements the existing literature on this topic, which typically falls into one of the following categories:

- Reports that are comprehensive in their review of the challenges at the nexus of agriculture, climate, and food security—or key elements within that nexus—and that are prescriptive in their solutions, but that do not provide quantitative mitigation data, e.g., WRI's "Creating a Sustainable Food Future" (2013)[7], The (U.K.) Government Office for Science's "Foresight. The Future of Food and Farming" (2011)[8], and The Global Partnership on Nutrient Management's "Our Nutrient World" (2013)[9].
- Reports that provide quantitative meta-analyses of the GHG mitigation potential in agriculture but are either limited to a single sector or country, or are not designed to provide implementation recommendations, e.g., FAO's "Tackling Climate Change Through Livestock" (2013)[10], USEPA's "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030" (2013)[11], China-U.K. SAIN's "Economic Potential of Greenhouse Gas Mitigation Measures in Chinese Agriculture" (2013)[12], Duke University's T-AGG reports[13], and the agriculture chapter of the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment[14].
- Journal articles and technical reports that provide a detailed mitigation analysis of a single agricultural mitigation intervention or a suite of interventions, e.g., Woolf et al. (2009)[15], Conant et al. (2010)[16], Hristov et al. (2013)[17], Hillier et al. (2012)[18].

This analysis and recommendations are based on individual countries. Interventions need to be locally appropriate and acceptable. Ultimately, the details of any mitigation strategy will be highly dependent on country contexts. Our recommendations prioritize countries for action based on GHG reduction potential, political context, and synergies with other strategies or activities. Yet, we are aware that our selection reflects incomplete information, and therefore almost certainly contains flaws. We may have overlooked important mitigation opportunities due to a lack of knowledge of a particular country's socio-economic contexts and political circumstances. We also recognize that there are many other ways this report could have been structured. Instead of providing recommendations by country, we could have structured the report around actors (e.g., national governments, multi- and bi-lateral financial institutions, corporations and farmers), or specific commodities (e.g., beef, dairy, rice and corn). In the Final Remarks Section, we share some preliminary thinking on how some of the recommendations in this report could be clustered or combined.

Based on these assumptions we have selected 12 strategies for interventions that collectively hold mitigation potential of more than 5 Gt CO_2e per year in 2030.

1.3

STRUCTURE OF THE REPORT

The first part of this report identifies the sources of emissions and assesses the technical mitigation potential of agriculture. Chapter 2 begins with an analysis of the sources of emissions, and continues with a review of the mitigation opportunities by region, country, sector, and agricultural commodity.

The second part of this report, Chapters 3-5, presents recommended strategies on the most relevant and promising agricultural mitigation opportunities. Building on the technical assessment of mitigation potential in Chapter 2, we assess the political or economic feasibility and identify priority areas for mitigation based on the feasibility of engagement. Chapters 3-5 are organized based on strategies and recommendations relating to:

- **Supply-side measures** that reduce GHG emissions or sequester carbon within the agricultural production systems.
- **Demand-side measures** that influence demand and emission reductions at the consumer end of the agricultural value chain.
- **Cross-cutting measures** that relate to the agricultural sector in general and include financing, transparency, and activities that increase the sustainability of agricultural supply chains.

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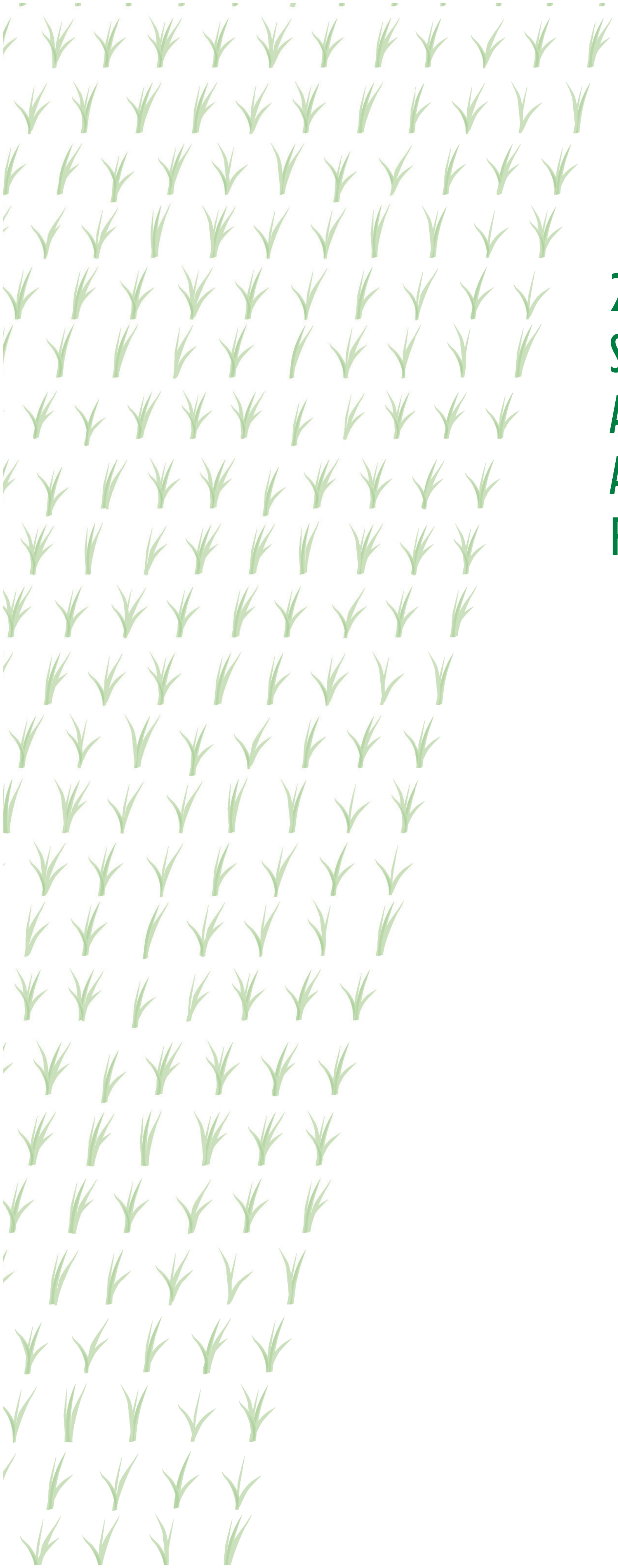


2.

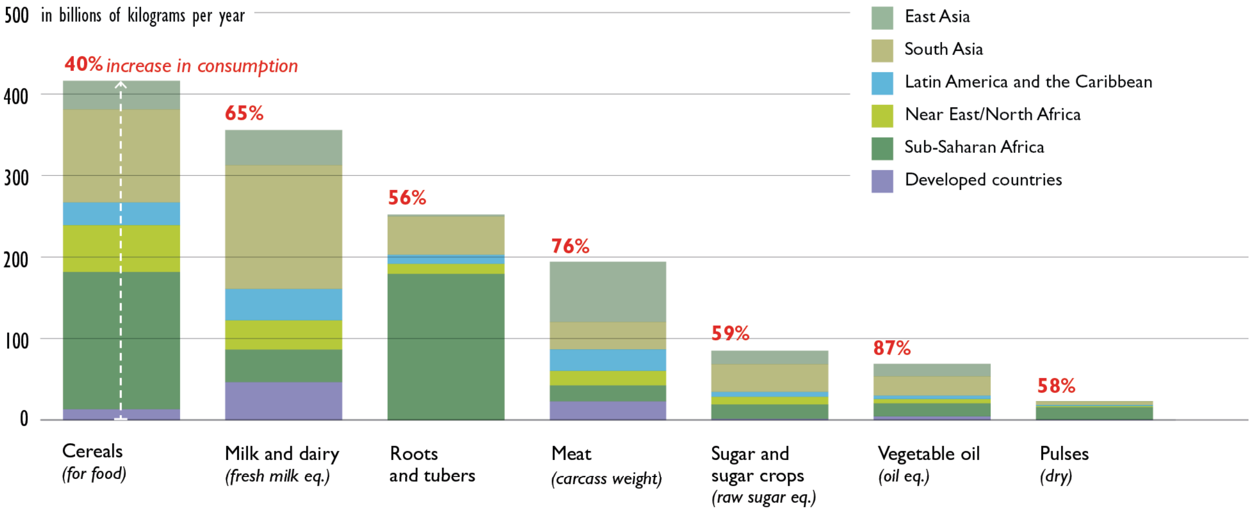
SOURCES OF AGRICULTURAL EMISSIONS AND MITIGATION POTENTIAL

2.1
CLIMATE CHANGE AND AGRICULTURE

2.1.1 Trends in agricultural production and emissions

Global agricultural production has nearly tripled over the last 50 years and is likely to increase another 50 percent or more in the first half of the 21st century as global population edges past 9 billion and rising incomes drive up per capita consumption.[1] Two-thirds of the growth in overall food demand is expected to come from Sub-Saharan Africa and South Asia.[2] Production of vegetable oils and animal products—products with a high GHG intensity—are expected to grow the most. Total demand for livestock products is likely to increase over 70 percent globally between 2005 and 2050.[3] Increasing demand for biofuels and animal feed will also drive rapid growth in maize and sugarcane production. See Figures 1 and 2 for projected growths in consumption.[4]

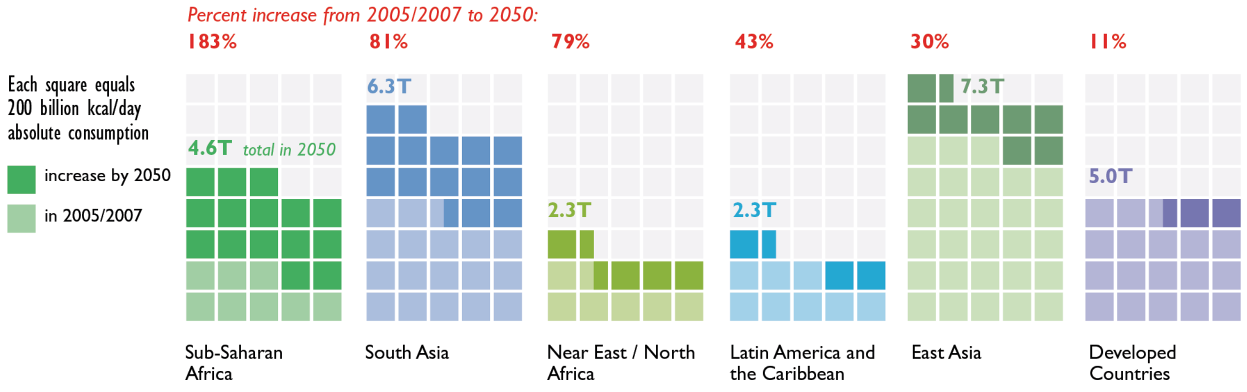
Figure 1: Growth in food consumption by 2050, relative to 2005-2007[5]



Source: CEA analysis based on: Alexandratos and Bruinsma, 2012.

Figure 2: Growth in total food consumption by 2050, relative to 2005/2007[6]

Total food consumption (kcal/day) in 2005/2007 and total increase by 2050. Light colored boxes represent absolute consumption in 2005/2007 and dark colored boxes represent the growth in absolute consumption from 2005/2007 to 2050.



Source: CEA analysis based on: Alexandratos and Bruinsma, 2012.

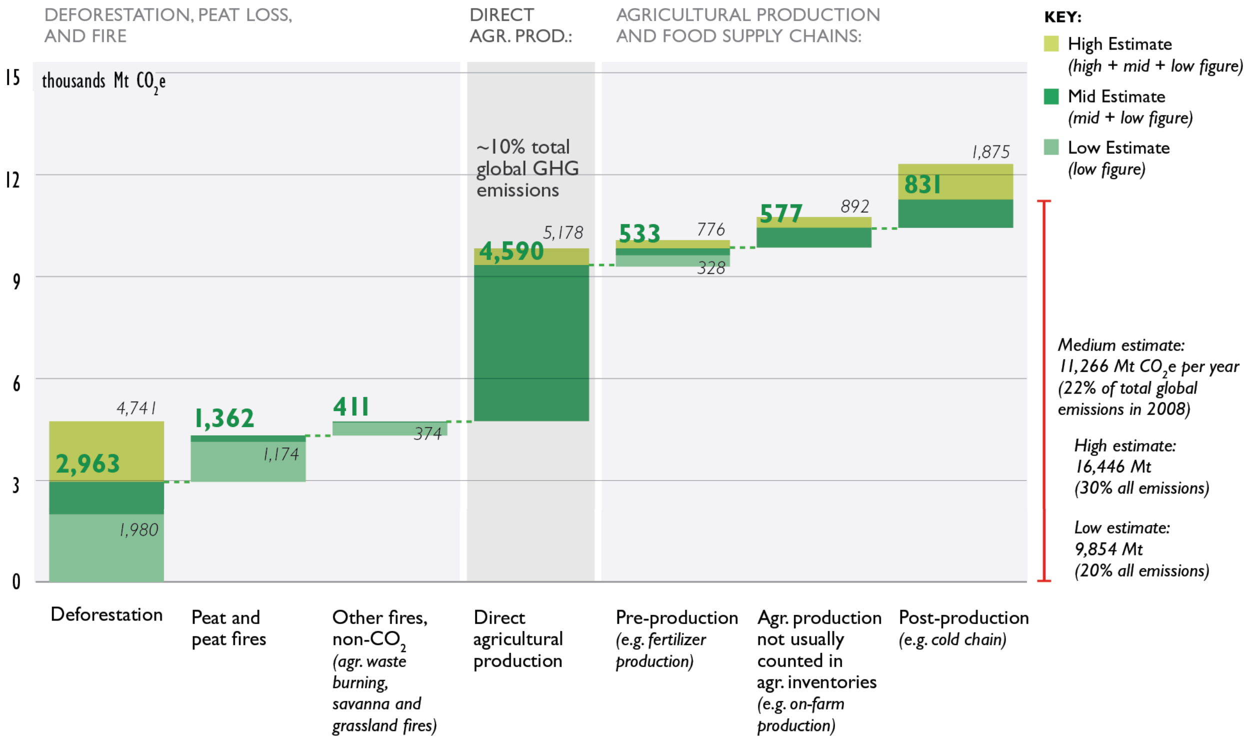
Emissions from the agricultural sector are very substantial, especially when accounting not only for emissions from direct production, but also for fossil fuel emissions along the agricultural supply chain, and emissions associated with agriculture's role in driving deforestation. Currently, roughly a fifth of global GHG emissions (CO_2e) come from these three sources of agriculture-related emissions. Of this, roughly 40 percent of this total comes from direct agricultural production, another ~40 percent from deforestation, peat loss and fires (much of which is driven by agriculture), and nearly 20 percent from the agricultural supply chain and on-farm machinery. See Figure 3 for global agricultural and land use emissions.

Over the last several decades, direct agricultural GHG emissions have been increasing steadily, in tandem with growing global agricultural production. Although agricultural emissions and production will likely always be tightly correlated, emissions are projected to grow slightly more slowly than production, due to expected efficiency gains. From 2010 to 2020, projections for annual growth in global agricultural emissions range from 0.8 to 1.3 percent while projections for agricultural production is expected to grow, on average, between one and two percent.[7] Fractions of percentages make a difference at the global scale. Direct agricultural emissions in Sub-Saharan Africa are expected to grow the most rapidly (30 percent between 2010 and 2030). Emissions in South America (excluding Brazil), the U.S., and Southeast Asia are expected to grow between 20 to 25 percent over the same period. China and India will also have notable emissions growth rates over this time period, at roughly 15 percent each. Comparatively, emissions are expected to grow more slowly in the E.U. (3 percent) and Brazil (7 percent).[8]

Though the models that project land use conversion in the coming decades lack precision, they indicate that the amount of land that will be converted into agricultural production is likely to grow by 6 to 30 percent for crops and by 5 to 25 percent for pastures.[9] These land conversions will add significantly to the emissions footprint of agriculture.

Figure 3: Global agriculture and land use change emissions[10]

The years associated with these data vary and reflect the most recent year for which good data is available. For deforestation, data is the average annual rate from 2000–2005 (by way of comparison, the rate of global deforestation by area has increased in recent years). Peat and fire emissions show the range of emissions for the years 2000–2008. Direct agricultural production emissions are from 2008. Other supply chain emissions are from varying years, mostly 2004–2010.



Source: CEA analysis based on: Harris et al., 2012.; FAOSTAT 2008; EDGAR 4.2, Vermeulen et al., 2012; Bellarby et al., 2008; Chen and Zhang, 2010; Lal, 2004; Smith et al., 2007; Steinfeld et al., 2006; Van Oost et al. 2012; Wakeland et al., 2012; Weber and Matthews, 2008.

2.1.2 Direct agricultural emissions

We define ‘direct agricultural emissions’ as those emissions typically found in agricultural greenhouse gas emissions inventories. Typically, these inventories only include nitrous oxide (N_2O) and methane (CH_4) emissions. Both are potent greenhouse gases: nitrous oxide has a global warming potential 296 times that of carbon dioxide and methane has a global warming potential 23 times that of carbon dioxide (CO_2). Sources of direct agricultural emissions with related percentages are listed in Table 1.

Table 1. Sources of direct agricultural emissions[11]

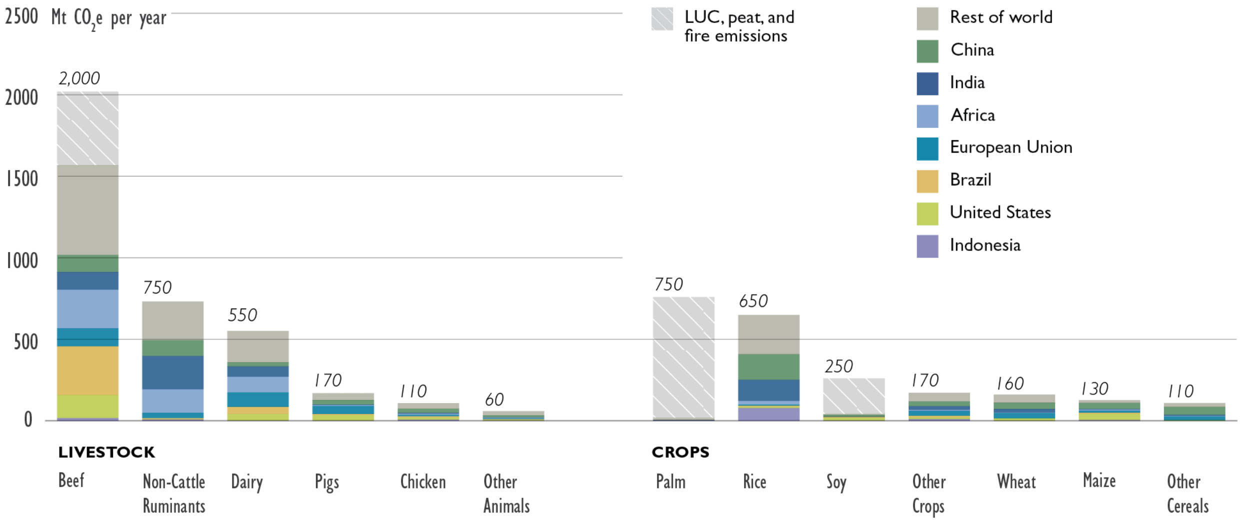
Sources of emissions	%
Enteric fermentation Ruminants (e.g., cattle, sheep, goats, water buffalo) emit CH_4 directly as a byproduct of digestion.	43%
Manure deposited on grazing lands Manure and urine that falls on grazing lands causes N_2O emissions.	16%
Synthetic fertilizers N_2O emissions from soils resulting from large amounts of nitrogen fertilizer added to crops.	15%
Rice production Most rice production systems result in CH_4 emissions from anaerobic decomposition on flooded fields. This fraction represents CH_4 emissions from rice only. N_2O emissions from fertilizers are counted in 'synthetic fertilizers'.	11%
Stored manure Livestock manure and urine cause both CH_4 emissions through increased decomposition in wet storage systems, as well as N_2O emissions in dry storage systems.	7%
Crop residues Crop residues that remain on agricultural lands are a source of N_2O.	3%
Manure deposited on croplands Manure is another source of nitrogen fertilizer for crops, resulting in N_2O emissions.	2%
Cultivation of organic soils N_2O emitted from drained organic soils.	2%

Source: FAOSTAT 2010.

Direct agricultural emissions can be split into two categories: crops and livestock. The allocation of emissions to these categories depends on accounting methodologies and is complicated by interconnections between the two such as manure used as a crop fertilizer and crops grown for animal feed. Livestock-related emissions account for over 70 percent of direct agricultural emissions if manure is left on pasture[12] and emissions from crops grown for feed are counted as livestock emissions. A recent report of the Food and Agriculture Organisation of the United Nations (FAO) calculates the entire lifecycle of livestock including fertilizer production to grow feed crops, livestock-driven deforestation, processing and transportation, to be 7.1 Gt, or roughly 14.5 percent of all human-induced greenhouse gas emissions.[13] While we don't have a comparable global life-cycle emissions assessment for food crops, it is likely much smaller.

Cattle and other ruminants are responsible for the vast majority of livestock emissions, and account for over 60 percent of all direct agricultural emissions. Rice accounts for nearly half of the emissions from crops, or 15 percent of direct agricultural emissions. When emissions are compared across commodities (see Figure 4), beef leaps to the top of the list. Beef, soy, and palm oil also contribute greatly to emissions from land use change (including deforestation, peatland conversion, and fires).

Figure 4: Global emissions by commodity, 2008[14]



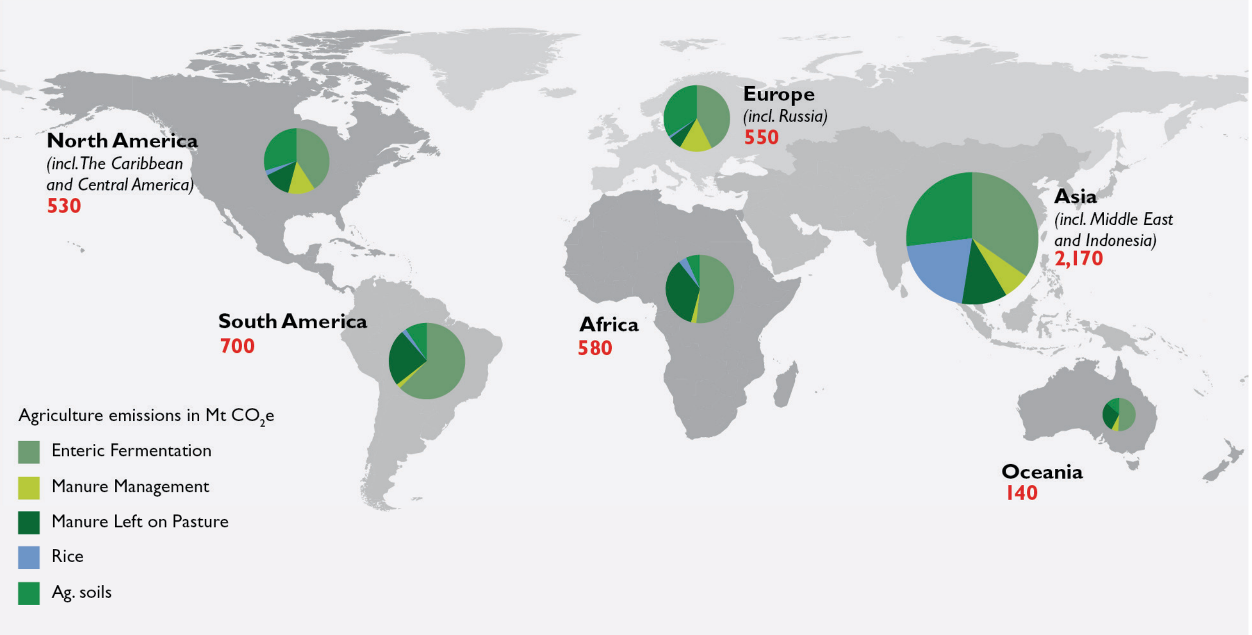
Source: CEA analysis based on: FAOSTAT 2008; Gerber et al., and personal communications with Paul West; Institute on the Environment, University of Minnesota.

Geographically, Asia, which holds 60 percent of the world's population and 30 percent of its land area, accounts for 45 percent of global agricultural GHG emissions. Asia also has the most diversified sources of agricultural emissions, primarily because it is the dominant producer of rice. Four countries, China, U.S., India, and Brazil account for over 40 percent of direct agricultural emissions. If the E.U. were counted as a single country, it would rank as the world's third largest emitter and would account for 10 percent of direct global agricultural emissions.

Figure 5 highlights the different composition of direct agricultural emissions from different regions of the world. Large cattle populations cause enteric fermentation to account for the majority of agricultural emissions in South America. Manure left on pasture is a sizable portion of agricultural emissions in regions that primarily graze livestock, while managed manure is sizable only in areas that have industrialized livestock production. Emissions from rice are only significant in Asia.

Figure 5: Global emissions by region, 2010[15]

"Agricultural soils" includes synthetic fertilizers, manure applied to crops, field application of crop residues, and nitrous oxide from cultivated organic soils. Area of pie charts scaled to regional emissions.



Source: CEA analysis based on: FAOSTAT 2010.

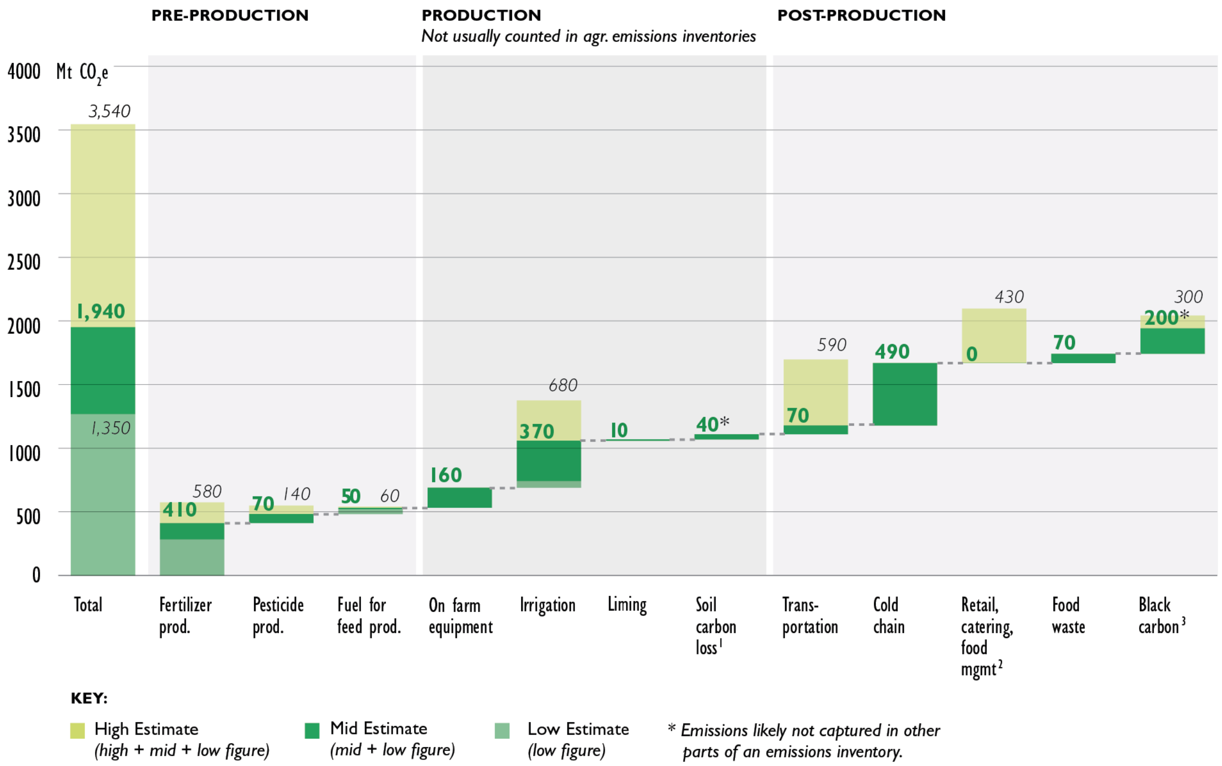
2.1.3 Supply chain emissions

Emissions associated with the agricultural supply chain account for approximately 1.9 to 3.5 Gt CO_2e per year (see Figure 6). Most of these emissions are fossil fuel emissions and are captured in other sections of national emission inventories (e.g., transportation, energy). Fertilizer production and energy used for irrigation and cold chain are the most significant sources of agricultural supply chain emissions (when direct agricultural emissions and emissions from land use change are excluded). There is a large mitigation opportunity associated with improving industrial efficiency along these supply chains. Black carbon emissions from agricultural fires are also a notable contribution to radiative forcing, as black carbon is a potent short-term forcer.[16]

This report does not address mitigation opportunities from the agricultural supply chain or on-farm fossil fuel emissions with the important exception of fertilizer production. Section 3.1.2 includes recommendations for addressing emissions from fertilizer production in China. We have addressed only China because fertilizer production in China is particularly emissions-intensive and there is a very significant opportunity to improve efficiencies. Additionally, some recommended interventions that apply across the entire agricultural supply chains are covered in Chapter 5, Cross-Cutting Measures.

Figure 6: Agricultural supply chain emissions[17]

Most estimates are of emissions from the mid-2000s.



CO_2 from urea application and emissions associated with food retail activities and food preparation could not be accurately determined. The latter is probably a significant source of emissions.

1) Net fluxes, highly uncertain.

2) From the available information it was unclear to what extent this category overlapped with cold chain and transportation emissions; thus, it was only included in the high bound scenario

3) Black carbon emissions associated with agricultural burning. Black carbon emissions from heating and cooking stoves would add an additional 1300 Mt CO_2e per year.

Source: CEA analysis based on: Vermeulen et al., 2012.; Bellarby et al., 2008; Chen and Zhang, 2010; Lal, 2004; Smith et al., 2007; Steinfeld et al., 2006; Van Oost et al. 2012; Wakeland et al., 2012; Weber and Matthews, 2008.

2.1.4 Land use change emissions

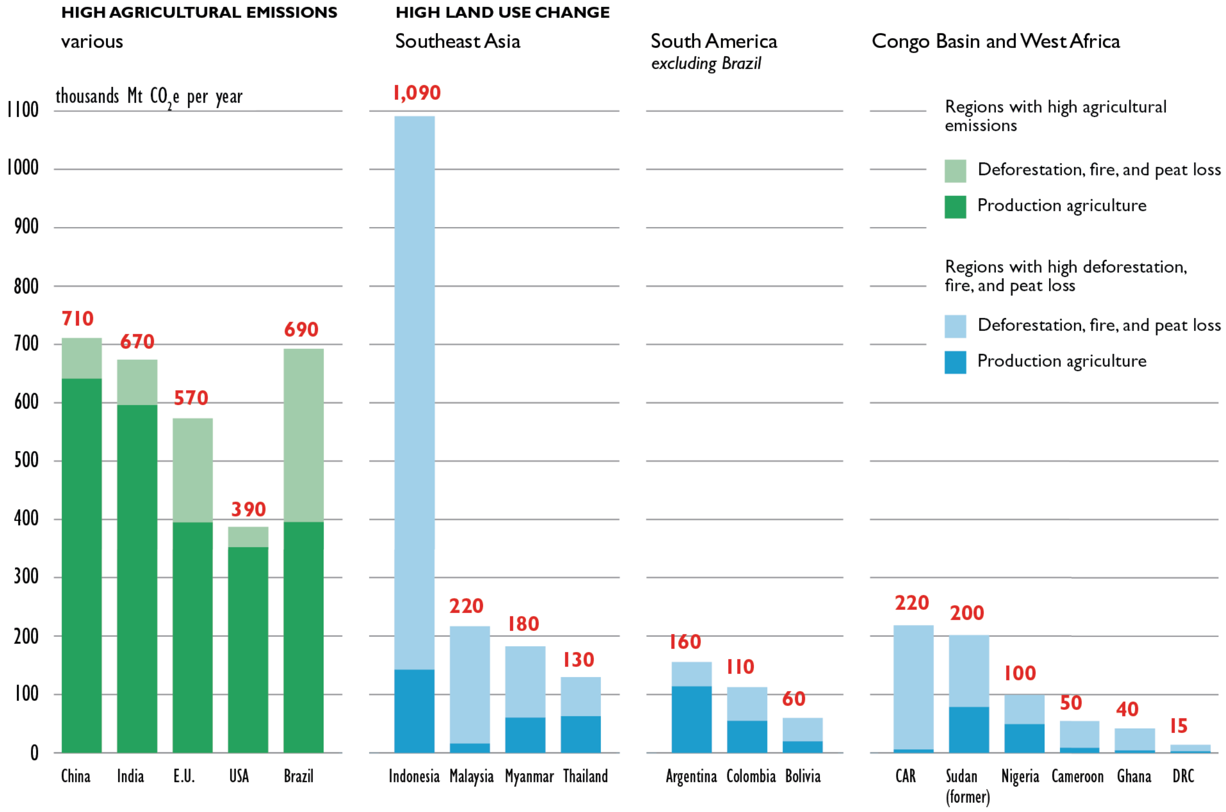
For the purposes of this report, ‘land use change emissions’ include deforestation, conversion of peatlands to agricultural lands, agricultural waste burning, and grassland and savanna burning. Together, this category emits between 3.5 and 7.8 Gt CO_2e per year.[18] Although the drivers of deforestation, degradation and fires are diverse and vary depending on geography and socio-economic context, agriculture is a leading driver of land use change in most parts of the world. Literature that attempts to attribute a percentage of forestry and land use change emissions to its various drivers estimate agriculture’s contribution as high as 80 percent.[19]

In general, South America and Southeast Asia are hotspots for deforestation, and the Congo Basin is poised to become a hotspot in the coming years. Cattle ranching, small-scale agriculture, and commercial crops such as palm oil, soybeans, rubber, and pulp and paper are all significant drivers of deforestation (see Text Box 1). In most cases, multiple sectors, crops, and socio-economic factors have a role in driving deforestation over time. While livestock and crops may be the proximate cause of forest conversion, in many countries, the revenue generation needs of local governments, weak central government presence in remote forest areas, poor monitoring, and a lack of enforcement or accountability enable illegal and rapid exploitation.

Fires are also a notable source of agriculture-related emissions, at roughly 400-800 Mt CO_2e per year. Based on the available emissions data, savanna burning accounts for the majority of emissions from fires. Agriculture is directly and indirectly linked to savanna and grassland burning, as burning is sometimes part of shifting cultivation, or used to encourage new grass growth for livestock feed, or used to create a barrier around fields. However, it is unclear to what extent agriculture is a primary cause for fires across regions. The emissions estimate above does not include short-cycle carbon losses, only methane and nitrous oxide from fires. Furthermore, it fails to capture the full radiative force of fires, which also emit black carbon, ozone, and aerosols. Fire timing and location also matter. High latitude fires, such as those used to clear winter wheat in Russia and Ukraine, alter the albedo of the Arctic. Agricultural fires can also take a heavy toll on air quality and human health. While reducing them is not a main recommendation of this report, doing so would have many important benefits. Figure 7 illustrates agriculture emissions by country, including emissions from land use change.

Figure 7: Total agriculture and land use change emissions, by country[20]

Most deforestation emissions are based on average annual emissions from 2000 to 2005, except for Brazil which is from 2010. Fire, peat loss, and agricultural production emissions are from 2008. While this graph attempts to captures a snapshot in time, it is important to remember that emissions, particularly land use change related emissions, vary significantly over time.



Source: CEA analysis based on: Harris et al. 2012; FAOSTAT, 2008; EDGAR v4.2; Ministerio da Ciencia, Techologia e Inovação, Brasilia, 2013.

Text Box 1. Deforestation drivers across regions[21]

In Indonesia, the number one global hotspot for deforestation, palm oil and pulp and paper are the primary agricultural drivers of deforestation. Roughly one-third of Indonesia's deforestation occurs on peatlands. Peatland conversion is particularly serious as these are among the most carbon dense lands on the planet, and because peatlands are often cleared by fires which cause both additional emissions and serious health and air quality hazards.

Malaysia and mainland Southeast Asia has been experiencing significant population and economic growth, with consequent agricultural expansion. Rubber in particular has been replacing shifting cultivation in the highlands, although some countries in this region, such as Vietnam, have seen an increase in forest cover.

In Brazil, cattle ranching and soybean cultivation have historically been the primary agricultural drivers of deforestation in the Amazon, though sales of timber from cleared land have also played a critical role in financing the conversion of forests to agricultural land. Brazil's historically weak land tenure policies and enforcement have enabled this pattern. Over the past decade, Brazil has made tremendous strides in reducing its rate of Amazon deforestation, though the past year has n an upturn in land clearing. The Cerrado of Brazil, the savanna region to the southeast of the Amazon Basin, is the agricultural heart of Brazil and continues to be heavily cleared to support agricultural growth and production. Although its woodlands contain notable stocks of carbon, the Cerrado region has few legal protections or protected areas. In recent years, land use change emissions may equal those from the Amazon.

While deforestation has been generally decreasing in the Brazilian Amazon, it has been increasing in much of the rest of the Amazon Basin, particularly in **Peru, Colombia and Bolivia.** Subsistence farming, cattle ranching, and commercial crops including palm oil, soy, coffee, and sugarcane are eroding standing forests.

Except for a small amount of shifting cultivation, agriculture has not historically been a driver of deforestation and degradation in the **Congo Basin.** However, recent years have seen commercial palm, rubber, and sugar plantations emerge as significant drivers of forest loss in the Congo. Commercial timber harvest has also expanded. Degradation is also a significant concern, with subsistence activities, charcoal production, unsustainable logging, and livestock grazing in the forest all contributing.

2.1.5 Uncertainty

It is important to note that there are high levels of uncertainty associated with agricultural emissions and mitigation data. Most global emissions inventories, including the new data set published by FAOSTAT, which is the one primarily used in this report, use Tier One[22] methodology. This approach pairs activity data reported by individual countries with regionally-specific emissions factors for the emissions source. Experts and published literature suggest that error generally ranges from 10 to 100 percent, although some emissions categories can have error bars of up to 400 percent.[23] The nitrous oxide emission from both synthetic and organic fertilizers, and sources and sinks from soil carbon fluxes have particularly high levels of uncertainty. Because error bars are rarely included in the literature and data sets associated with agricultural emissions, we have not included error bars in our analysis.

Certainty around mitigation potential is also generally low. Our sources came from either models (which typically do not provide ranges or error bars) or meta-analysis of experimental data (which often provide ranges). We chose not to provide ranges in this report because we were focused on profiling the high-end of mitigation potential—or technical potential. However, in some cases we have included multiple estimates for the same mitigation opportunity to show results based on different assumptions or different methodologies as a way of providing a degree of sensitivity analysis.

2.2
MITIGATION POTENTIAL

Table 2 provides an overview of the technical potential for GHG mitigation in the agricultural sector, calculated by country and emitting sector. Technical mitigation potential represents the emissions reductions and agricultural carbon sequestration possible with current technologies, ignoring economic and political constraints. This analysis provides a snapshot of mitigation potential in the year 2030, compared to a hypothetical baseline in which no mitigation from production agriculture is attempted, beyond what is expected given current adoption and intensification trends. To determine our baseline emissions for 2030, we scaled 2010 emissions reported by FAOSTAT by growth factors published in EPA 2012 applied by country and sector.[24] Our projection shows that agricultural emissions will scale from 4.67 Mt CO_2e in 2010 to 5.19 Mt CO_2e in 2030. The growth factors used in the EPA report were generated by the IFPRI IMPACT model, except for rice harvesting which is based on FAPRI's "U.S. and World Agricultural Outlook." They are provided in Table 1 in Annex 3 of this report. It is important to note that because this report calculates the mitigation potential based on the potential to reduce emissions compared with a baseline, the trajectory of the baseline has a big influence on the resulting estimates. The growth factors used to calculate the 2030 baseline assumed by this report is a major assumption underlying most of the mitigation calculations presented in this report, though they themselves have a high level of uncertainty.

This analysis represents a synthesis of existing published literature and data. We used a range of approaches to determine the mitigation potential for the main categories of interest: enteric fermentation, manure management, rice management, fertilizer application to crops, carbon sequestration on croplands, grazing lands and in agroforestry systems, and changes in demand. In the case of enteric fermentation, manure, rice, and fertilizer emissions, mitigation potential was calculated as a percentage reduction from 2030 emissions. The mitigation potential of biochar was calculated based on the lifecycle mitigation benefits of producing biochar from a range of feedstocks and then applying it to croplands. Our estimates for soil carbon sequestration in grazing lands and from agroforestry are pulled directly from literature, or from an aggregation of a range of regional studies. In some cases we cited published analyses directly. In other cases, we developed our own assessments based on existing data. In a select number of cases, we relied on unpublished work shared with us by leading scientists in the field.

Because agricultural emissions and mitigation have such high uncertainty levels, technical mitigation potential can be difficult to estimate precisely; one could reasonably use different data or assumptions than those employed in this report and obtain a divergent estimate of technical mitigation potential.

The methodologies for each category of mitigation are further described in Annex 3.

Boundaries of this analysis

The analysis is intended to help readers understand the relative magnitude and tractability of mitigation opportunities.

- These estimates are imprecise. The data on agricultural greenhouse gas mitigation is complicated by uncertainty in emissions, variable testing conditions for mitigation interventions, and a range of other factors that make it very difficult to precisely estimate mitigation potential.
- No attempt was made to quantify the economic mitigation potential because of a lack of data on the economic costs and benefits of interventions across a range of geographies and production systems.

It should be understood that the entire technical mitigation potential will not be achievable given political and economic constraints.

- This data is not modeled. The mitigation potentials presented for different sectors may not be fully additive. However, insofar as it was possible, elements of the analysis were designed to be consistent with one another and avoid potential double counting of mitigation opportunities.
- This analysis does not include specific assumptions about the pathway that would be used to get to the 2030 mitigation potential (e.g., the technology and emissions in each year from 2013–2030).
- Limited data and resources prevented a robust quantitative analysis of the following issues, which in some cases are discussed narratively in the report: restoration of degraded or abandon lands, avoided deforestation, supply chain interventions (with the exception of fertilizer production in China), fossil fuel off-sets from bioenergy from feedstocks that do not have competing uses, and on-farm machinery and irrigation.

Mitigation categories

To be widely applied, mitigation strategies must ensure that yields are not harmed and must also be cost-effective. Additionally, strategies that support the resilience of the agricultural sector to a changing climate are more likely to be readily embraced by farmers and policy makers alike. This section profiles those countries, sectors, and approaches that represent the largest mitigation opportunities. Chapters 3–5 provide a discussion of the major opportunities, taking into account the economic, political, and social feasibility of interventions.

This report estimates a total of between 5.4 to 6.3 Gt CO_2e of mitigation potential in the agricultural sector through a combination of emissions reduction, sequestration of carbon in agricultural systems, and major shifts in consumption patterns. These levels of mitigation would make the agricultural sector roughly GHG neutral. While a GHG neutral agricultural sector is conceptually possible given the benefits of carbon sequestration (while it is actively occurring), this scenario is highly unlikely. One limitation of this analysis is that it does not account for the impacts that supply and demand interventions would have on one another. For example, if the global population significantly reduced the amount of meat it consumed, then the technical mitigation potential from the livestock sector would not be as large, because the baseline projection would change. Conversely, if major efficiency gains are made on the supply-side, then the mitigation potential realized by shifts in consumption would be reduced. Further, some of the assumptions made by this assessment are unrealistic. For example, this assessment assumes that the entire global population could generate about 2 Gt CO_2e of emissions reductions by converging on a diet constrained to 90 grams of protein per day. Although there are major portions of the global population that do not eat this much meat, these totals are significantly lower than the current global average. We have included this calculation primarily to demonstrate the outsized impact of dietary shifts over large populations.

Mitigation from agriculture can result from three types of interventions:

1. **Reducing the emissions intensity along the entire agricultural supply chain, including avoided land use change driven by agriculture.** This report estimates that roughly 1.8 Gt CO_2e per year of GHG mitigation is possible by 2030 from emissions reductions from enteric fermentation, manure management, both nitrous oxide and methane emissions from all crops, as well as improved efficiencies in fertilizer production in China. This portfolio of emissions reduction options, which are based on interventions that are technically feasible today, represent a reduction of roughly 30 percent in direct agricultural emissions below a business as usual scenario. Beyond the 30 percent range, it will be difficult to reduce GHG emissions further without reducing or substantially shifting

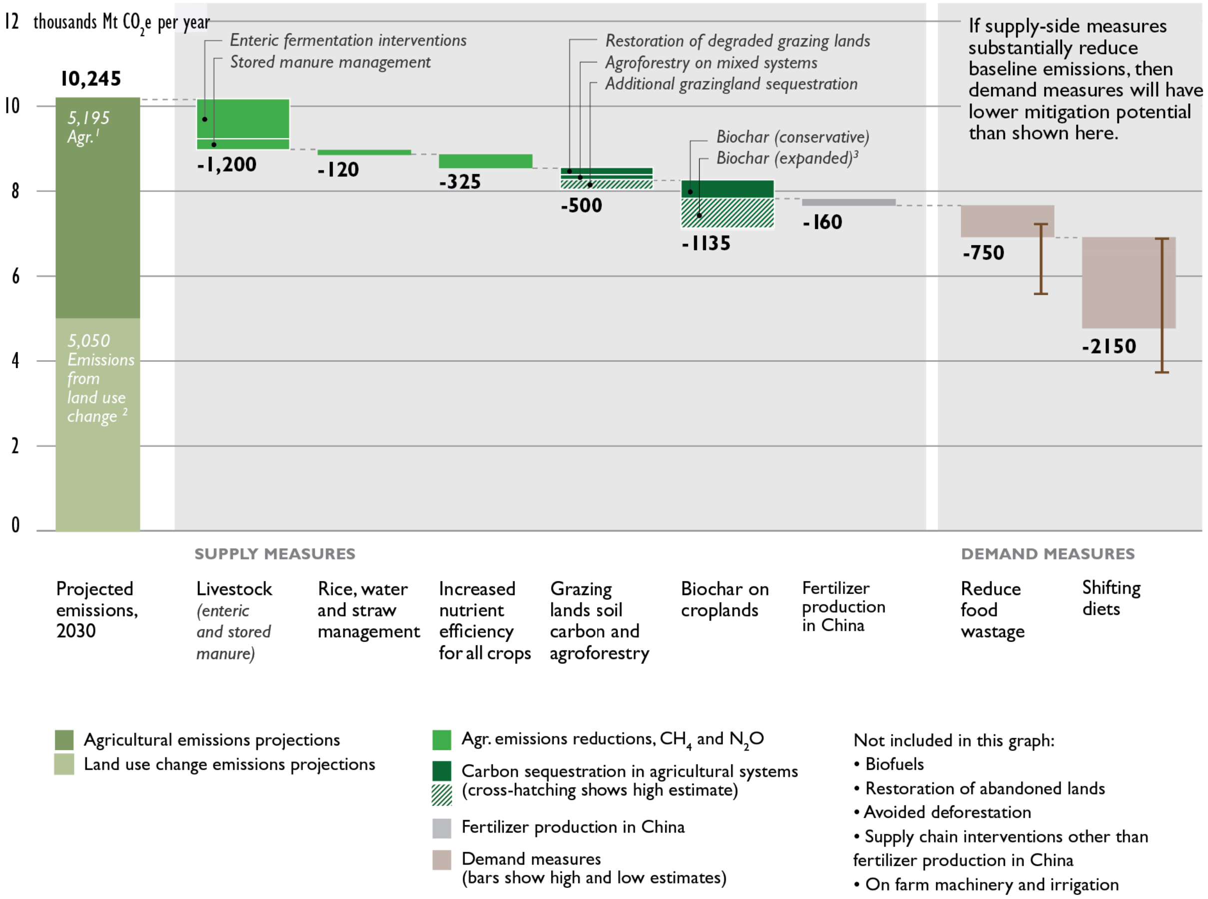
the mix of agricultural production, or major technological breakthroughs such as anti-methane vaccines for ruminants or crop breeding for nitrogen use efficiency.

Additionally, substantial emissions reductions are possible by reducing land use change driven by the conversion of forests to agricultural lands. These emissions reductions should be possible, in theory, through sustainable intensification of agricultural lands combined with strong forest conservation policies. These dynamics are discussed further in Section 3.1.1, though this report does not estimate an emissions reduction potential from reduced deforestation.

2. **Sequestering additional carbon in agricultural systems.** This report estimates between 0.7 and 1.6 Gt CO_2e per year could be sequestered in cropland and grazing land soils, and in agroforestry systems by 2030. It is possible to sequester more carbon in agricultural lands, both in the soil and in above-ground biomass through a range of soil, crop, and livestock management practices. However, there continues to be a great deal of uncertainty in the science of soil carbon sequestration (e.g., how much carbon certain practices sequester over time), the degree to which carbon sequestration practices are economically viable for farmers, and the availability of biomass (e.g., where will the carbon come from and are there competing uses for these sources of carbon). Additionally, carbon sequestration is complicated by the realities of saturation and permanence. Levels of carbon in the soil and above-ground biomass eventually reach saturation, at which point additional sequestration is not possible. In the future, that carbon can also be released back into the atmosphere depending on the crop management practice and climatic conditions. See Section 3.1.4 for further discussion of carbon sequestration. Nevertheless, when layered on top of emissions reductions, sequestration in agricultural lands has the potential to make an important contribution to the technical potential for GHG mitigation in agriculture, at least in the near-to mid-term.
3. **Reducing overall agricultural production (e.g., by reducing food loss and waste or demand for biofuels) or shifting away from high-carbon intensity agricultural products such as meat from ruminants.** This report estimates that nearly 3 Gt CO_2e could be mitigated from changes in diets and reductions in food loss and waste (food wastage), compared with a business as usual scenario. About 75 percent of this estimate comes from changes in diet and the other 25 percent from reductions in food wastage. These major shifts in demand for agricultural products represent emissions reduction of roughly 55 percent of direct agricultural emissions.[25] Again, while this estimate may seem very aggressive, it is provided to demonstrate the impact that changes in consumption could have. Note that shifts in consumption towards high-carbon foods, above what is projected, could *add* to global emissions by an equal order of magnitude.

Figure 8 summarizes the set of mitigation opportunities, including emissions reductions (dark green), agricultural carbon sequestration (light green) and demand-side interventions (olive green). Figure 9 shows the geographic distribution of mitigation potential. Table 2 provides mitigation potentials by sector and country for the top agricultural economies, along with some commentary on the opportunities.

Figure 8: Mitigation opportunities in agriculture, 2030[26]



For details about the methodology used to derive this figure, please see Methods annex.

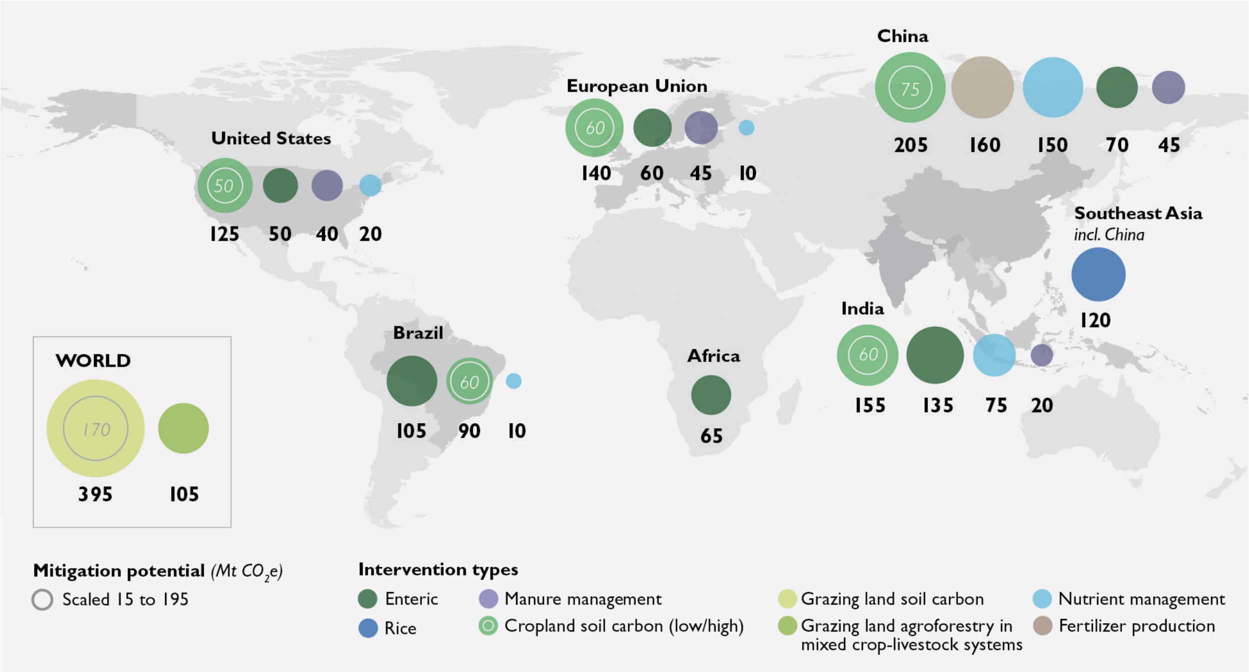
1. N_2O and CH_4 from direct agriculture, but not including methane from soils or fire emissions. Based on FAO emissions scaled by country and sector emissions growth factors predicted by EPA 2012.
2. Highly uncertain; estimated based on linear scaling of current ration of land use change/agriculture emissions. Comparatively, GCAM estimates much lower LUC emissions in 2030, ~700 Mt CO_2e-yr^{-1}.
3. Includes the mitigation potential of both sequestration and avoided emissions from biochar production, as well as feedstocks from biomass crops on abandoned and degraded lands.

Source: CEA analysis based on multiple sources. See Annex 3 for methodology and sources.

Figure 9. Global mitigation opportunities (technical potential)[27]

Setting aside economic and political constraints, the greatest technical opportunities to reduce agricultural greenhouse gases from direct agricultural are centered on a few key geographies: U.S., E.U., China, India, and Brazil.

There is a high level of uncertainty in estimates of carbon sequestration on croplands and grazing lands. In this analysis we have provided an upper estimate and a lower estimate of mitigation potential based on different assumptions and/or different analyses. The two circles show the mitigation potential using the high and low estimates.



United States

125. Croplands: *Soil carbon sequestration (biochar), high*

50. All ruminants: *Enteric fermentation reduction*

50. All livestock *Stored manure management*

20. All crops *Nutrient management*

Brazil

105. All ruminants: *Enteric fermentation reduction*

90. Croplands: *Soil carbon sequestration (biochar), high*

10. All crops: *Nutrient management*

European Union

140. Croplands: *Soil carbon sequestration (biochar), high*

60. All ruminants: *Enteric fermentation reduction*

45. All livestock: *Stored manure management*

10. All crops: *Nutrient management*

India

155. Croplands: *Soil carbon sequestration (biochar), high*

135. All ruminants: *Enteric fermentation reduction*

75. All crops: *Nutrient management*

20. All livestock: *Stored manure management*

China

205. Croplands: *Soil carbon sequestration (biochar), high*

160. Supply chain: *Fertilizer production*

150. All crops: *Nutrient management*

70. All ruminants: *Enteric fermentation reduction*

45 All livestock: *Stored manure management*

Southeast Asia (incl. China)

120. Rice: *Water and rice straw management*

Greater Horn of Africa

65. All ruminants: *Enteric fermentation reduction*

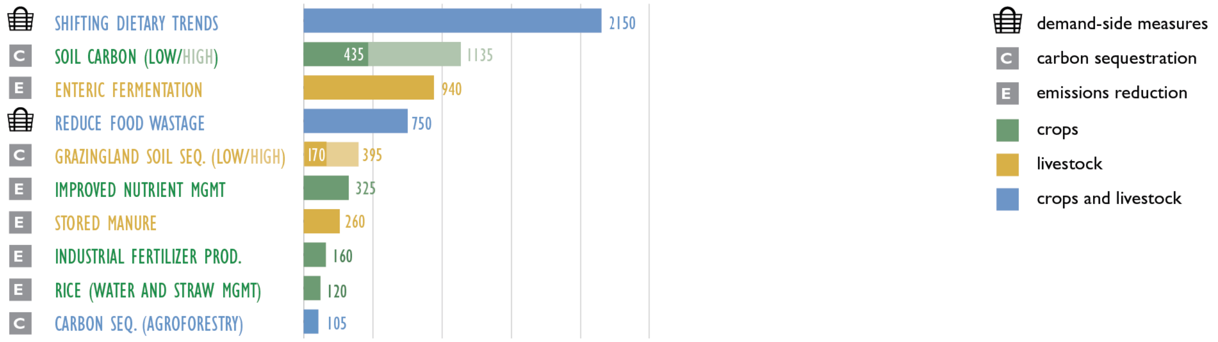
World

395. Grazing Lands: *Soil carbon sequestration, high*

105. Grazing Lands: *Agroforestry in mixed crop-livestock systems*

Source: CEA analysis based on multiple sources. See Annex 3 for methodology and sources.

Table 2. Mitigation opportunities by sector and country in 2030 (Mt CO_2e)



MITIGATION CATEGORY | **REGION / COUNTRY** | **DETAILS**

SHIFTING DIETARY TRENDS

WORLD 2,150

Meat and dairy, especially from ruminants, are high carbon products and consumption of these commodities are rapidly increasing.

The carbon intensity of food items varies dramatically. Meat and dairy, especially from ruminants, are high-carbon products and consumption of these commodities is rapidly increasing due to increasing income and populations in emerging countries. Efforts to reduce demand, shift meat consumption to lower carbon alternatives (e.g., from beef to poultry), or curtail growth should be explored in both developed and emerging economies. This mitigation estimate assumes that the entire global population adopts a "healthy diet" based on recommendations from Harvard Medical School which prescribe 90 grams of protein per day. Although there are major portions of the global population that do not eat this much meat, and large portions of the global population that are unlikely to adopt such meat heavy diets for cultural and/or religious reasons, these totals are significantly lower than the current global average.

SOIL CARBON SEQUESTRATION FROM BIOCHAR APPLIED TO CROPLANDS

WORLD 435 (low) / 1,135 (high)

	(low)	(high)
CHINA	75	205
INDIA	60	155
BRAZIL	60	90
USA	50	125
EU	60	140
HORN OF AFRICA	N/A	
INDONESIA	N/A	
PAKISTAN	N/A	
ARGENTINA	N/A	
AUSTRALIA	N/A	
MEXICO	N/A	
ETHIOPIA	N/A	
VIETNAM	N/A	

This report relies on an analysis of the mitigation potential from global adoption of biochar to provide estimates for soil carbon sequestration potential on croplands. Two estimates are shown, using different assumptions about available feedstocks and the inclusion of avoided emissions in the life-cycle calculations. According to this analysis, the largest opportunity for GHG mitigation from biochar is through the use of rice residues. Sugar cane residues is also an important feedstock. China and Brazil are regions with particularly strong potential for biochar. In terms of broader attention to soil carbon sequestration, Sub-Saharan Africa is critical region because of the strong links between soil fertility and food security.

ENTERIC FERMENTATION

All ruminants

WORLD 940

CHINA	70
INDIA	135
BRAZIL	105
USA	50
EU	60
HORN OF AFRICA	65
INDONESIA	10
PAKISTAN	45
ARGENTINA	30
AUSTRALIA	20
MEXICO	20
ETHIOPIA	25
VIETNAM	5

Brazil: Brazil's large cattle populations provide one of the most cost effective opportunities to reduce enteric methane emissions. Improving the forage quality on grazing lands in Brazil could increase the stocking densities, increase the productivity of the herd and thus reduce the number of animals needed to support a given level of production (thus reducing emissions). Additional carbon sequestration on these lands would be a co-benefit.

India: The mitigation potential shown here reflects the opportunity for all of India's ruminant population. However, India's large and growing population of dairy livestock (both cattle and buffalo) provides a particularly ripe opportunity for enteric methane emissions. The mitigation potential in the dairy sector alone is 70 Mt COe$_2$ per year. For the dairy sector, access to better quality stover and other feed is the priority (as the animals are rarely grazed). Improved diets will increase the productivity of these animals.

EU and US: While there is still fairly significant potential to reduce enteric fermentation in cattle across Europe and the US, these systems are highly industrialized already; cattle are fed high quality diets and are produced very efficiently. Additional gains require high-cost additives and supplements which typically do not increase productivity and, in some cases, have negative impacts.

Sub-Saharan Africa: Although there are sizable livestock populations across Sub-Saharan Africa which are typically fed low-quality diets, the opportunity for mitigation is low in this region because so many of these animals are not grown for market but rather kept for financial security, labor, and subsistence. Improving feed would likely not reduce the size of the herds.

MITIGATION CATEGORY | **REGION / COUNTRY** | **DETAILS**

REDUCED FOOD WASTAGE

WORLD 750

Food wastage is largely a byproduct of inefficiency and there are vast opportunities for cost savings and emissions reductions along the entire supply chain.

In the energy and transportation sectors, there has been a tremendous amount of attention placed on improving the efficiency of the systems. A comparable effort has not been initiated in the agricultural sector, but is desperately needed since food postharvest loss and consumer waste of food across the supply chain is over 30 percent in most countries.[i]

i) Godfray et al., 2010.

GRAZINGLAND SOIL CARBON SEQUESTRATION

WORLD 170 (low) / 395 (high)

The countries with the biggest opportunities for mitigation are those that have large areas of grazing land that are important to their agricultural economy (e.g. Brazil, China, Kenya, Ethiopia, Mongolia).

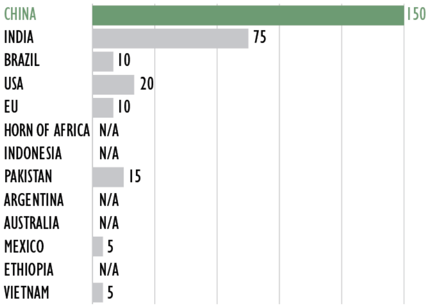
This report provides two estimates of mitigation potential from soil carbon sequestration in grazing lands, drawing from multiple sources in the scientific literature. The carbon sequestration potential of grazing lands is one of the most uncertain areas of agricultural mitigation. The lower estimate shown here only estimates the soil carbon sequestration potential associated with rehabilitating overgrazed grasslands. It should be considered a conservative estimate because there are opportunities for soil carbon sequestration on grazinglands that are not degraded.

There is soil carbon sequestration potential in grazing lands in many regions of the world. The countries with the biggest opportunities for mitigation are those that have large areas of grazing land that are important to their agricultural economy (e.g. Brazil, China, Kenya, Ethiopia, Mongolia).

Brazil: In Brazil there is an enormous amount of pasture that is already managed, but is marginally productive. Productivity on these grazing lands could improve a lot with a change in management practices. The potential productivity gains mean that pasture improvements are inline with producer incentives. Any effort to improve the carbon sequestration of grazing lands in Brazil dovetails well with efforts to reduce enteric fermentation emissions through improved forages (see above).

IMPROVED NUTRIENT MANAGEMENT

WORLD 325



China: Over the last few decades, China has become the global hotspot for overuse of synthetic fertilizers. Most farmers in China could reduce fertilizer application rates by 30-60% without harming yields.[ii] Aggregate nutrient use efficiency rates across China could double.

India: India is an emerging hotspot for over application of fertilizer. Although there are many parts of India where access to fertilizer is still limited and fertilizer is still under-applied, increasingly it seems to be following the path of China in terms of over-application.

US: Although American farmers are relatively efficient with fertilizer inputs per unit of output, roughly 65% of croplands have potential for better timing, rate, or method of nutrient application.[iii]

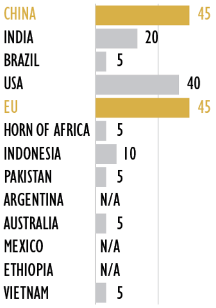
Sub-Saharan Africa: Most croplands across Sub-Saharan Africa receive too little fertilizer. Increasing rates of fertilizer use across the region would greatly benefit yields, without much of an increase in emission. With increased yields, higher volumes of crop residues would be available for soil carbon sequestration and increased soil fertility.

ii) Ju et al., 2009
iii) Ribaudo, M. (2011) "Reducing agriculture's nitrogen footprint: are new policy approaches needed?" United States Department of Agriculture: Economic Research Service.

EMISSION REDUCTIONS FROM STORED MANURE

All livestock

WORLD 260



China: The opportunity for reducing emissions from stored manure is significant in China, where management practices have not yet been widely implemented in concentrated feeding operations and where massive growth is anticipated in confined pig and poultry populations.

EU and US: There is significant opportunity to reduce emissions from stored manure in the US, which has been slow to adopt mitigation measures such as methane digesters. There is still room for improvement in the EU, although this region has probably already addressed the low hanging fruit as it has been faster to adopt digesters.

Although there are some low-cost and low-tech mitigation practices for better management of stored manure, the best options are costly and do not improve the productivity of livestock sectors. There are some low-cost and low-tech mitigation practices for better management of stored manure, but the best options are costly and do not improve the productivity of livestock sectors. However, there are very significant co-benefits of improved treatment of stored manure in any country, most notably water quality improvements. Further, both methane digesters and compost facilities can create valuable products (bioenergy or biogas, and soil enhancements, respectively). In some markets, these products will be profitable enough to warrant the upfront investment. However, in most markets some kind of subsidy will be required.

MITIGATION CATEGORY | **REGION / COUNTRY** | **DETAILS**

EMISSIONS REDUCTIONS FROM INDUSTRIAL FERTILIZER PRODUCTION

WORLD N/A

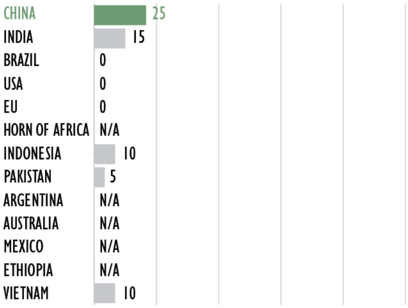
China: In China, emissions from fertilizer production are particularly high because coal is used as a feedstock (as opposed to natural gas) and equipment is largely outdated and inefficient. Vast improvements could be made over time by investments in new equipment and industry consolidation.

iv) Zhang et al., 2013

WATER AND STRAW MANAGEMENT

Irrigated rice systems

WORLD 120



Southeast Asia: Rice has one of the highest carbon footprints of any crop because of the methane generated from cultivating in wet systems. Mid-season drainage in irrigated systems and improved management of rice straws can provide significant emissions reductions and are cost effective where water is expensive.

CARBON SEQUESTRATION FROM AGROFORESTRY

WORLD 105

Agroforestry systems may well have adoption potential across a wider range of agricultural systems, however data on the mitigation potential for agroforestry is limited.

This report includes an assessment of the carbon sequestration potential from agroforestry systems adopted in mixed crop-livestock systems in humid and tropical highland areas of the developing world. Agroforestry systems may well have adoption potential across a wider range of agricultural systems, however data on the mitigation potential for agroforestry is limited. Agroforestry may be particularly appropriate for grazing lands or mixed crop-livestock systems as they can provide shade and nutritional benefits for livestock and are less likely to displace crops.

1) A detailed discussion of the methodology employed for all of these estimates is provided in Annex 3;
2) This report does not provide country-level estimates for carbon sequestration on grazinglands, agroforestry, fertilizer production outside of China, or demand side measures. It also only provides country level estimates for biochar application for some countries;
3) This report does not provide estimates for soil carbon sequestration on croplands for practices other than biochar application and agroforestry in mixed systems because of data limitations and because of potential double-counting between these practices and biochar. Table 2 in Annex 3 provides additional information on country and regional carbon sequestration potential.

Source: CEA analysis based on multiple sources. See Annex 3 for methodology and sources.

2.2.2 Economics of agricultural mitigation

As noted in Section 2.2, above, this report has calculated technical mitigation potential, not economic mitigation potential. Unfortunately, cost data for mitigation in the agricultural sector is extremely limited. The U.S. EPA has published a few global marginal abatement cost curves for the agricultural sector, most recently in 2013.[28] Several country-specific cost curves have been published recently as well (e.g., U.S., China, U.K.).[29,30,31] Additionally, work is currently underway at the FAO to produce a global cost curve for the livestock sector. The few cost curves that do exist are difficult to apply globally either because they do not provide sufficient detail to support the kind of analysis undertaken by this report, or they are specific to individual countries.

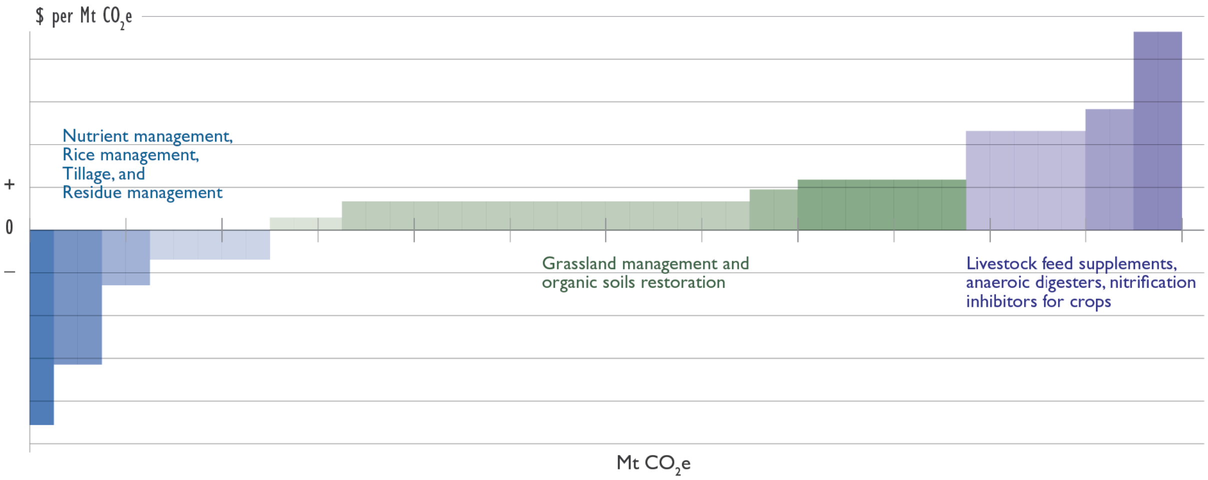
Mitigation options and costs will vary significantly by region due to a number of factors including: variation in local natural resources, the maturity of local markets and distribution chains, willingness of national and local governments to subsidize, promote, and regulate mitigation practices, and variation in what practices have already been implemented. However, most cost curves that have been published show fairly consistent structures. That is, there are several generalizations that can be made regarding the relative cost and potential size of the mitigation options:

- Nutrient and fertilizer management, rice management, and tillage and residue management on croplands tends to be negative- or low-cost, with moderate relative mitigation potential.
- Grasslands management and organic soils restoration is generally low or moderate cost with fairly significant relative mitigation potential.
- Methane flaring and digestion are generally moderate-cost with moderate relative mitigation potential.
- Livestock supplements/additives to reduce enteric fermentation are relatively costly with small relative mitigation potential.

The figure below is representational of cost curves in the agricultural sector and is provided to illustrate a qualitative sense of the economics of agricultural mitigation.

Figure 10. Illustrative marginal abatement cost curve for the agricultural sector

This illustrative cost curve for the agricultural sector is not based on actual data. It is a demonstration.



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[1] Alexandratos N., Bruinsma J. (2012). *World agriculture towards 2030/2050, the 2012 revision.* (ESA Working paper No. 12-03). Rome, Italy: Food and Agriculture Organization of the United Nations.

[2] Ibid.

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

[4] Alexandratos, N., Bruinsma J. (2012). See fn #1

[5] CEA analysis based on Alexandratos, N., Bruinsma J. (2012).

[6] CEA analysis based on Alexandratos, N., Bruinsma J. (2012).

[7] GreenAgSim 2011 (personal communication); GCAM 2013 (personal communication); Verge, X., Dyer, J., Desjardins, R., Worth, D. (2007). Greenhouse gas emissions from the Canadian dairy industry in 2001. *Agricultural Systems*, 683-693.; Alexandratos, N. et al. (2012).

[8] U.S. Environmental Protection Agency. (2012). *Global Anthropogenic Non-CO$_2$ Greenhouse Gas Emissions: 1990-2030.* Washington, D.C.: U.S. Environmental Protection Agency.

[9] Smith, P., Gregory, P., van Vuuren, D., Obersteiner, M., Havlik, P., Rounsevell, M., Woods, J., Stehfest, E., Bellarby, J. (2010.) Competition for land. *Philosophical Transactions of The Royal Society, B 365*, 2941-2957

[10] CEA analysis of many sources, primarily: Harris, N., Brown, S., Hagen, S., Saatchi, S., Petrova, S., Salas, W., Hansen, M., Potapov, P., Lotsch, A. (2012). Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science, 336,* 1573-1576 (deforestation).; Food and Agriculture Organization of the United Nations, (2013). Retrieved 2013-2014, from http://faostat.fao.org. (direct agriculture); The Emissions Database for Global Atmospheric Research (EDGAR) of the European Commission Joint Research Center and the Netherlands Environmental Assessment Agency, dataset version 4.2, November 2011. (peat loss and fire); Vermeulen, W., Kok, M. (2012). Government interventions in sustainable supply chain governance: Experience in Dutch front-running cases. *Ecological Economics, 83,*183-196.; and other sources specific to supply chain emissions. See Figure 6 for full list of supply chain sources. Note that this graph includes all land use change emissions, not just land use change emissions that are driven by agriculture.

[11] Food and Agriculture Organization of the United Nations, (2013). FAOSTAT. Retrieved 2013-2014, from http://faostat.fao.org.

[12] In most agricultural inventories, "manure left on pasture" is combined with "manure on crops" and "synthetic fertilizers" in a category often called "agricultural soils", somewhat obscuring all sources of livestock-related emissions.

[13] Gerber, P.J. et al. (2013). See fn #7

[14] CEA analysis, utilizing data from Gerber, P.J. et al. (2013).; Paul West, Institute on the Environment, University of Minnesota (personal communication); Food and Agriculture Organization of the United Nations, (2013). FAOSTAT. Retrieved 2013-2014, from http://faostat.fao.org.

[15] Food and Agriculture Organization of the United Nations, (2013). FAOSTAT. Retrieved 2013-2014, from http://faostat.fao.org.

[16] Bond, T. C., Doherty, S.J., Fahey, D.W., Forster, P., Berntsen, T., DeAngelo, B., Flanner, M., Ghan, S., Karcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P., Sarofim, M., Schultz, M., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S., Hopke, P., Jacobson, M., Kaiser, J., Kilmont, Z., Lohmann, U., Schwarz, J., Shindell, D., Storelvmo, T., Warren, S., Zender, C. (2013). *Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118*, 5380–5552.

[17] Vermeulen, W., Kok, M. (2012). Government interventions in sustainable supply chain governance: Experience in Dutch front-running cases. *Ecological Economics, 8,* .183-196; Bellarby, J., Foereid, B., Hastings, A., Smith, P. (2008). *Cool Farming: Climate impacts of agriculture and mitigation potential.* Amsterdam: Greenpeace International.; Chen, G.Q., B. Zhang, (2010). Greenhouse gas emissions in China 2007: Inventory and input-output analysis. *Energy Policy, 38*, 6180-6193. ; Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science, 304,*1623-1627; 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. I*n 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, United Kingdom: Cambridge University Press.; Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C. (2006). *Livestock's Long Shadow: Environmental Issues and Options.* Rome, Italy: Food and Agriculture Organization of the United Nations.; Van Oost, K., Verstraeten, G., Doetterl, S., Notebaert, B., Wiaux, F., Broothaerts, N., Six, J. (2012). Legacy of human-induced C erosion and burial on soil-atmosphere C exchange. *Proceedings of the National Academy of Sciences in the United States of America (PNAS), 109,* 19492-19497.; Wakeland, W., S. Cholette, K.Venkat. (2012). Green Technologies in Food Production and Processing. J.I. Boye and Y. Arcand (eds.), *Food Engineering*

Series. Springer Science+Business Media, LLC.; Weber, C., and Matthews, H.S. (2008). Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science and Technology, 42,* 3508-3513.

[18] CEA analysis utilizing EDGAR v4.2 (2000-2008); Harris, N., Brown, S., Hagen, S., Saatchi, S., Petrova, S., Salas, W., Hansen, M., Potapov, P., Lotsch, A. (2012). Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. S*cience, 336*, 1573-1576; UN 2012; Brazil UNFCCC inventory 2012. This analysis does not include forest degradation which can also be caused by agriculture, particularly livestock grazing and shifting cultivation.

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

[20] Deforestation emissions are based on annual emissions 2000-2005; other LUC emissions are from 2008. Agriculture emissions are from 2008. Source: CEA analysis using Harris et al. (2012): 1573-1576; Food and Agriculture Organization of the United Nations, 2010.; EDGAR v4.2, and "Estimativas anuais de emissoes de gases de efeito estufa no Brasil", Ministerio da Ciencia, Techologia e Inovacao, Brasilia, Brasil 2013. Note that this graph includes all land use change emissions, not just land use change emissions that are driven by agriculture.

[21] Expert interviews

[22] The UNFCCC has established different methods for estimating emissions from most CO_2e source and sink categories. There are three tiers, moving from the least precise to the most precise. Tier I employs country or regional level emissions factors. Tier II uses emissions factors which are more precisely defined. Tier III uses models and/or inventory measurement systems tailored to address country-specific conditions.

[23] European Environment Agency. (2012). *Annual European Union greenhouse gas inventory 1990-2010 and inventory report 2012.* Copenhagen, Denmark: European Environment Agency.

[24] U.S. Environmental Protection Agency. (2012). *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2030. Washington, D.C.: U.S. Environmental Protection Agency.* Washington, D.C.: U.S. Environmental Protection Agency.

[25] Assuming 1.5 Gt CO_2e per year emissions reduction potential from food waste and between 4.3 Gt CO_2e per year and 6.4 Gt CO_2e per year emissions reduction from diet shits, compared with a baseline of 11.9 Gt CO_2e per year in 2050. These numbers were halved to generate 2030 mitigation potential. Scenarios taken from Stehlfest, E., Bouwman, L., van Vuuren, D.P., den Elzen, M., Eickhout, B., Kabat, P. (2009). Climate benefits of changing diet. *Climatic Change*, 83-102. These scenarios were generated using an integrated assessment model (IMAGE 2.4) and Smith, P., Haberl, H., Popp, A., Erb, K., Lauk, C., Harper, R., Tubiello, F., de Siqueira Pinto, A., Jafari, M., Sohi, S., Masera, O., Bottcher, H., Berndes, G., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E., Mbow, C., Ravindranath, N., Rice, C., Abad, C., Romanovskaya, A., Sperling, F., Herrero, M., House, J., Rose, S. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*: 2285-2302.

[26] Note: This chart shows technical mitigation potential, i.e. by how much emissions could be reduced through a full deployment of available best practices and technology. Realizable, economical potential is likely to be significantly lower. Estimates based on CEA analysis. See Annex 3 for methodology and sources.

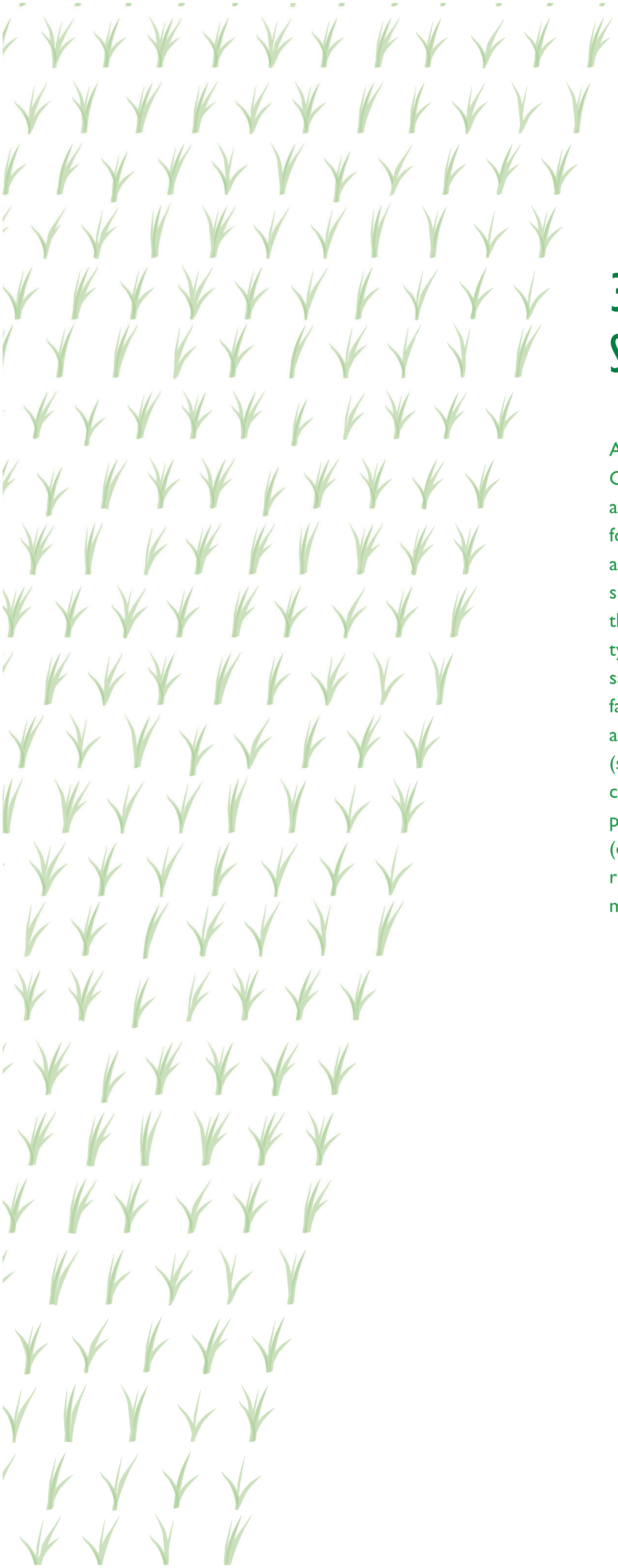
[27] Estimates based on CEA analysis. See Annex 3 for methodology and sources.

[28] United States Environmental Protection Agency. (2013). *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030.* Washington, D.C.: United States Environmental Protection Agency.

[29] ICF International. (2013). Greenh*ouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States.* Washington, D.C.: US Department of Agriculture.

[30] Wang, W., Moran, D., Koslowski, F., Nayak, D.R., Saetnan, E., Smith, P., Clare A., Lin, E., Guo, L., Newbold, J., Pan, G., Cheng, K., Yan, X. Cardenas, L. (2013). Economic Potential of Greenhouse Gas Mitigation Measures in Chinese Agriculture. (Policy Brief No. 8.). UK-China Sustainable Agriculture Innovation Network (SAIN),

[31] Moran, D., MacLeod, M., Wall, E., Eory, V., Pajot, G., Mathews, R., McVittie, A., Barnes, A., Rees, R.M., Moxley, A., Williams, A., Smith, P. (2008). *UK Marginal Abatement Cost Curve for the Agriculture and Land Use, Land Use Change, and Forestry Sectors out to 2022, with Qualitative Analysis Options to 2050.* UK Government's Committee on Climate Change.



3.

SUPPLY-SIDE STRATEGIES

A large number of practices can be deployed to reduce GHG emissions associated with the production of crops and livestock. Multiple intervention options are available for every source of emissions, and the effectiveness of any single intervention will depend greatly on the specifics of the relevant agricultural system. Interventions that reduce the emissions intensity of production are typically in line with productivity gains and/or cost savings, and are thus often in the best interest of the farmers. However, emissions intensification practices also carry the risk of environmental or social trade-offs (see Section 3.1 Sustainable Intensification). In other cases, mitigation practices do not have an impact on productivity, but may help farmers meet other objectives (e.g., water quantity savings from mid-season drainage in rice systems or water quality improvements from better management of stored manure).

3.1

SUSTAINABLE INTENSIFICATION

Background

Feeding a world of nine billion people by 2050 will require a substantial increase in food production.[1] Agricultural output can be increased either by expanding or intensifying production. In terms of mitigation effectiveness, intensification tends to be preferable to expansion. Expansion can cause substantial emissions from the conversion of land with high carbon stocks, especially in forested areas with weak governance. However, in some cases expansion can be beneficial (i.e., when expansion brings degraded lands back into production). Intensification, on the other hand, will typically increase emissions efficiency (e.g., lower emissions per unit of product). If managed well, intensification can avoid land conversion because greater agricultural production occurs on the same area of land. Historically, demand has been met by a combination of intensification and expansion.

Although agriculture has been a major driver of deforestation over the past few decades, it is likely that overall deforestation rates would have been much higher had it not been for the land-sparing effects from agricultural productivity gains. Recent analyses have found that intensification has saved as much as 60 percent of global arable land from conversion over the last 50 years.[2] An analysis by Valin et al.[3] confirms that intensification of crop and livestock production has major potential for mitigating agricultural emissions in developing countries. Closing yield gaps for crops, and especially for livestock, avoids production emissions and land use change emissions on the order of 100–400 Mt CO_2e per year by 2050. Comparing this to a less fertilizer-intensive intensification pathway, the potential increases by 30 percent.

Text Box 2. What is intensification?

Intensification reduces the emissions intensity of agriculture. Intensification means 'producing more with less' and is the result of using inputs more efficiently or adding new inputs that address limiting factors of production. Conventional intensification practices are typically based on changes or increases in the use of direct inputs, such as improved varieties/breeds, agrochemicals, water and mechanization. In addition, a variety of agronomic practices is available, broadly aimed at optimized density, rotations and precision of farming methods.

Consequently, many of the strategies to reduce emissions from agricultural production in the supply-side Sections of Chapter 3 are intensification strategies. They lead to a reduction in absolute emissions only if production is held constant. They do, however, necessarily reduce emissions per unit of output. However, the implications of intensification are complex and incentives for intensification process need to be carefully evaluated to avoid perverse or opposite effects. Historical evidence of causality between yield increases and reduced expansion on a local level has been questioned.[4] More efficient production methods can reduce input costs and increase rents and returns, and, therefore, may encourage farmers to expand land use or further increase production. This phenomenon is called 'the rebound effect of intensification'. The degree to which this rebound effect occurs depends on a number of factors including elasticity of demand and prices, the impact that intensification has on production costs, and availability, suitability, and cost of additional land. For example the introduction of fast growing grass species in the Amazon made pastures more productive and profitable, but also indirectly incentivized large-scale deforestation. Though the likelihood of a rebound effect needs to be studied locally, the issue can be complicated by the global dimensions of agricultural commodity markets. In the analysis by Valin et al., cited above, at completely inelastic prices the mitigation potential would multiply from 100–400 to 1500 Mt CO_2e per year.

Considering the complexities surrounding intensification, this Section looks at managing interventions that aim at increasing yields more generally, while the following Sections focus on particular production systems and regions. The challenge is to support 'sustainable intensification,' a concept broadly aimed at increasing yield and meeting future demand by optimized efficiency of agricultural production across social, environmental and ethical dimensions of sustainability.[5]

Co-benefits and trade-offs

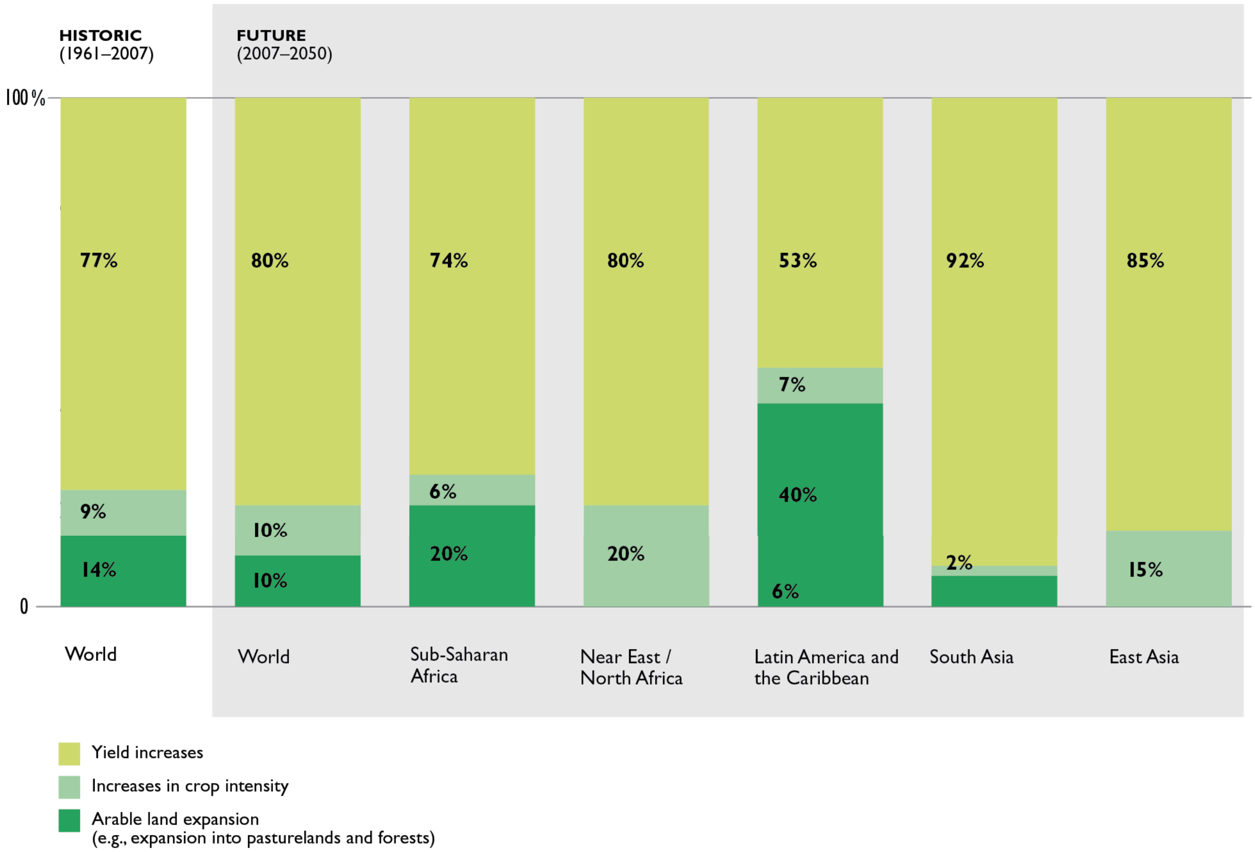
Co-benefits	Trade-offs
Food security Intensification can contribute to increased availability, stability and nutritional quality of food.	**Long-term Risks** Intensification can lead to structural vulnerabilities due to high dependency on modern inputs (e.g., agrochemicals, few varieties, and energy) combined with social (e.g., loss of livelihoods, cultural and social values) and environmental trade-offs (e.g., loss of biodiversity, animal welfare) that present a long-term threat to the sustainability[6] of global agriculture.
Economic Development Intensification offers opportunities for economic development. Particularly in inefficient systems, intensification can contribute to profitability and livelihood benefits for farmers.	**Social and Economic Exclusion** Intensification can have important socio-economic and cultural implications, for instance, where large populations directly depend on extensive, inefficient agricultural systems for their employment, livelihoods, social security and cultural traditions.
Environmental Quality Intensification can reduce pressure on land, forests and natural resources, and these benefits can extend beyond the local scale.	**Environmental Degradation** A number of technologies can have serious unintended consequences on the environment (e.g., groundwater pollution from fertilizer overuse, or, in livestock operations, negative effects due to the concentrated accumulation of manure, serious global health risks from antibiotic overuse and poor animal welfare).

Regional Focus

Increasing the efficiency of land and resource-use will be essential to meet rising demand for agricultural products and to improve food security for a growing global population. Globally, the majority of projected growth in crop production is expected to come from yield increases and to a smaller extent cropping intensity. While in Sub-Saharan Africa and Latin America substantial shares of additional production will be met by land expansion (see Figure 11).

Policy makers have recognized the need for public support to sustainable intensification as a means to support economic development and food security, and have made substantial pledges for public investments in several developing countries (e.g., in Africa, the Comprehensive Africa Agriculture Development Program). Sustainable intensification has also become a prominent strategy to reduce the role of agriculture as a major driver of deforestation, for instance in areas with high deforestation rates, such as in the Amazon, Central Africa and Asia. However, the potential intensification benefits and risks for trade-offs are particularly high in systems characterized by low productivity, which can still be found in many countries and sectors around the world, especially in developing and emerging economies.

Figure 11: Sources of agriculture production growth: crop yield, cropping intensity and expansion[7]



Source: CEA analysis based on: Alexandratos and Bruinsma, 2012.

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3.2

IMPROVING NITROGEN FERTILIZER MANAGEMENT AND PRODUCTION

Background

Nitrous oxide emissions stem from nitrogen fertilizers (both synthetic and organic) on croplands that have not been absorbed by plants, and leach instead into the environment. Fertilizer run-off contaminates surface and ground water quality and creates GHG emissions in the form of nitrogen oxide. The global technical mitigation potential for reducing nitrous oxide from soils is roughly 325 Mt CO_2e. Unfortunately, nitrogen balances in agricultural soils can vary greatly over space and time therefore it is difficult for farmers to know precisely when plants need the nutrients and how much nitrogen (and other nutrients) need to be applied at any one time. Consequently, farmers tend to over-apply fertilizer as an insurance mechanism against low yields.

To better manage fertilizer application, the basic approach is to increase the nitrogen use efficiency within the cropping system by better matching the nitrogen supply from fertilizers with the nitrogen demands of the crops. The following aspects of application can all play a role in helping match nitrogen supply and demand: 1) amount (apply only as much as can be taken up by the crop); 2) timing (apply when the crop needs the nutrients, e.g., split application); 3) type (balance of nutrients needed by the crop); and 4) placement (apply the nutrients where the plant can most easily reach them, e.g., inject nutrients into the soil and near the seeds instead of broadcasting). While these practices for better applying nitrogen are generally low-cost, they are knowledge-intensive and sometimes labor-intensive. There are a number of technologies and tools that can enable and improve optimal nitrogen use efficiency, including:

1. **Plant breeding and genetic modifications** to increase the uptake of nitrogen by the crop so that less fertilizer is needed to achieve the same yields.
2. **Better accounting and use of organic fertilizers** so that agricultural systems are less reliant on external inputs, and less likely to underestimate nitrogen inputs.
3. **Decision support tools for better managing input management** (timing, rate, and type). These tools can vary from simple, regionally-specific recommendations or leaf color charts to advanced remote sensing tools and decision support computer models linked to easy-to-use mobile phones.
4. **Regular soil testing** to develop appropriate nutrient management plans. In developing countries, soil testing can be done at a regional level, with recommendations made available to all farmers depending on region and crop.
5. **Technologically advanced fertilizers.** Examples include slow-release fertilizers which control the release of nutrients in lieu of double-application, and nitrification inhibitors which slow the degradation of nitrogen fertilizers so that the chemical components stay active and available to the plant for longer and do not leach into the environment. Advanced fertilizers are typically more expensive and are generally best considered second-phase technologies to be employed after basic improved management practices (e.g., better timing and rate of application) have been adopted.

In addition to the challenge of over-application and fertilizer management, the production of synthetic fertilizer is also a major source of GHG emissions and air pollution as it requires significant energy to produce, and uses fossil fuels (natural gas or coal) as feedstocks. Substantial improvements could be made through improvements in industrial efficiency. Efficiency gains are typically cost effective and would improve the productivity of the industrial sector, and are thus in the best interests of both producers and the government. There are no current figures for global mitigation potential from improved fertilizer production; estimates for China alone are 160 Mt CO_2e.[1]

Co-benefits and trade-offs

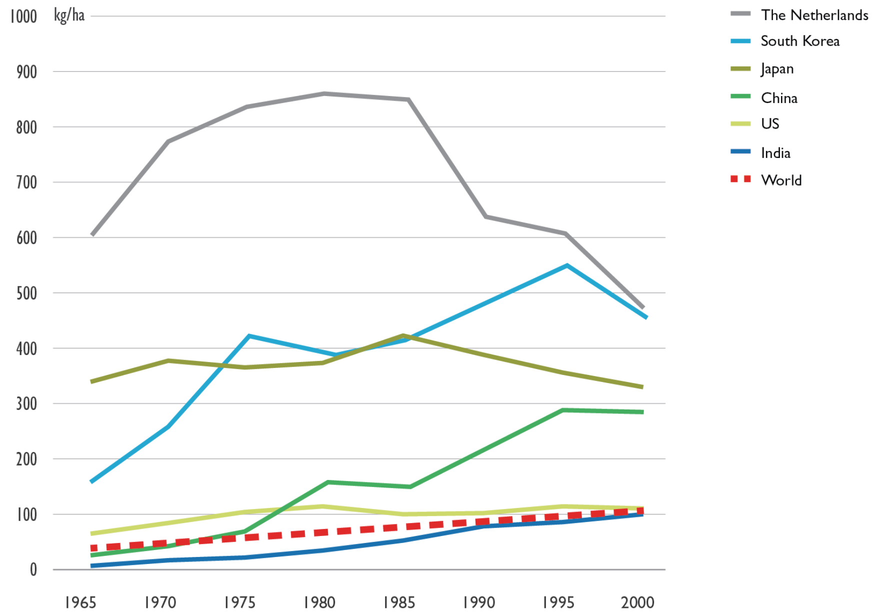
Co-benefits	Trade-offs
Cost savings Improving fertilizer application efficiency as well as improving industrial efficiencies in fertilizer production reduces capital costs.	**Potentially reduced yields** A perceived risk from farmers is that reducing nutrient applications could reduce yields. This is true if application is reduced below optimal application.
Increased yields Optimal use of fertilizer promotes long-term soil fertility and increases yields.	**Potentially higher labor and capacity needs** Changing fertilizer management practices can require either additional labor (e.g. split application) or technical knowledge on how and when to most efficiently apply the fertilizer.
Pollution abatement Increasing the nitrogen efficiency within cropping systems decreases leakage into the environment and contamination of surface and ground water. Additionally, reduced demand for synthetic fertilizer and improvements in fertilizer production significantly reduce air pollution.	**Availability of specific inputs** Fertilizer availability is a problem in many developing countries. Making the right type of fertilizer available for the specific crop is often difficult.
Enhanced health conditions Increased air and water quality from efficiencies in fertilizer management and production improves health conditions and reduces costs of public health systems.	

Regional Focus

Fertilizer management. Overuse of nitrogen fertilizers is a significant issue in most countries with highly industrialized, high-input agricultural systems (e.g., U.S. and E.U.) and in a few countries that are aggressively intensifying their agricultural systems (e.g., China). Although almost all systems can benefit from improved nitrogen use efficiency, there are a few areas where fertilizers are over-applied to such an extent that they constitute “low-hanging fruit” for reducing emissions with minimal yield impacts or expense. China, the U.S., and (to a lesser extent) India and the E.U. are all hotspots of nitrogen overuse, and account for nearly 80 percent of agricultural soil nitrous oxide emissions. Together, these countries account for a technical mitigation potential of roughly 255 Mt CO_2e per year (150 Mt in China, 20 Mt in the U.S., 75 Mt in India, and 10 in the E.U.).

China presents the most promising location for improving fertilizer application given large potential emissions reductions and additional economic and environmental co-benefits. Along with modern crop varieties, the use of fertilizer in China has increased significantly in recent years (see Figure 12). Average per unit area application of fertilizer is now several times higher than in the U.S.,[2] with particularly high application rates on vegetables and fruits.[3] Although increased fertilizer application was instrumental in increasing yields through the 1970s and 1980s, the efficiency of fertilizer use has greatly decreased in the last few decades and pollution of soils and water by fertilizers is a widely recognized problem. Most farmers in China could reduce fertilizer application rates by 30 to 60 percent without harming yields.[4]

Figure 12. Chemical fertilizer consumption per unit actual cultivation area (kg/ha), 1965–2000[5]



Source: He et al., 2007.

Excess nitrogen fertilizer use in China is a result of several intersecting drivers, some of which are common in most agricultural systems (e.g., risk aversion, insufficient information, economic disincentives) and some that are unique to China (e.g., labor constraints, farm ownership structures, inefficiencies in fertilizer production). For decades, the message to farmers in China has been 'more is better,' and few farmers have had an opportunity to acquire sound data or knowledge upon which to base their nutrient management regimes. The capacity of the agricultural extension service is weak, and there is little institutional priority on improved nutrient management. China's Ministry of Agriculture prioritizes yield gains over all else and is concerned about the potential for improved nutrient management to threaten yields. In addition, fertilizer retailers are often the main source of information for farmers on fertilizer usage.

There are also a number of economic factors related to the structure of the agricultural sector that hinder the adoption of better fertilizer management practices. Due to rapid urbanization in China, there are significant labor constraints in rural areas. Because the opportunity cost of labor is so high, most farms only receive a single application of fertilizer instead of the preferred split application. Furthermore, Chinese farmers are constrained in their ability to consolidate farmland. With an average plot size of about one acre,[6] most Chinese farms do not operate with economies of scale that make managing input costs worthwhile. In addition, the mix of crops grown has changed in recent years, with more fertilizer intensive crops such as vegetables becoming more important.[7] These crops use more fertilizer than cereals, and also commonly apply high rates of manure.[8]

The Soil Testing and Fertilizer Recommendation (STFR) program, launched in 2010, is the main national program to address the problem of nitrogen fertilizer overuse. The STFR covers all 2,498 agricultural counties, and around USD 1billion has been invested to date. The program involves testing soil properties and crop fertilizer needs to make location- and crop-specific fertilizer recommendations on the basis of which specialist nitrogen/phosphorus/potassium (NPK) mixture fertilizers are produced by 100 participating fertilizer firms. Fertilizers are then supplied by firms to farmers and guidance is provided in their application. Although there are indications from macro-level data that nitrogen fertilizer application rates are decreasing, there have been no comprehensive, micro-level assessments of the effectiveness of this program.

Accessible, user-friendly information for farmers on the use of new production methods is fundamental for inducing behavioral change on the ground. For farmers, it is important to know best application methods for the specific farming system, in particular because many farmers apply too much fertilizer to avoid yield losses. Chinese extension services are seen as weak, and in the past they also had a strong connection to the fertilizer industry. Therefore, exploring ways to reduce the knowledge gap and risk management behavior of farmers could provide important levers for improvement.

Fertilizer production. China also provides the highest potential for reducing GHG emissions by improving the efficiency of fertilizer production. Coal is used as the primary feedstock and equipment is largely outdated and inefficient. Vast improvements could be made over time by investments in new equipment and industry consolidation. Efficiency gains are typically cost effective and are in line with the government's industrial productivity goals.

Before the period of economic reform, China promoted domestic fertilizer production mainly through small-scale factories often using inefficient technologies. In 1982, more than half the national fertilizer output was produced by 1,227 small-scale factories.[9] Although policy makers have long been aware of the inefficiencies of smaller plants, the relative costs of energy and other investment costs enabled smaller factories to continue to be economically viable. Eradicating inefficient small-scale production was also difficult because until 1998, fertilizer production was a state monopoly sector. By 2000, 30 percent of fertilizer output was still due to more than 1,000 small-scale plants.

Technical options to improve the energy efficiency of nitrogen fertilizer production are well known in the industry and are supported by current GHG mitigation programs.[10] The project-based carbon finance mechanisms—joint implementation (JI) and the clean development mechanism (CDM)—of the Kyoto Protocol have catalyzed significant GHG reductions by channeling climate finance to industrial reduction projects. In 2010 and 2011 alone about USD 340million have been invested into nitrous oxide (N_2O) GHG reduction projects under CDM and JI, out of which USD 60million went to China.[11]

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[3] Zhang, W., et al. (2013). See fn #1

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[6] Hughes, M. and Ning, Y. (2010). Farmers slowly cultivate a new image. *China Daily*.

[7] The total area planted with vegetables in China increased from 3.3 million hectares in 1980 to 28 million hectares in 2008.

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[10] Zhang, W. et al. (2013). See fn #1

[11] Climate Focus data.

3.3

REDUCING EMISSIONS FROM ENTERIC FERMENTATION

Background

Enteric fermentation is part of the digestive process in herbivorous animals ('ruminants' such as cows, buffalos, goats, and sheep). These animals have a rumen, a large four-compartment stomach with a complex microbial environment. The rumen allows these animals to digest complex carbohydrates, a process that produces methane as a byproduct. Enteric fermentation is responsible for over 40 percent of direct agricultural emissions. Beef and dairy cattle account for roughly two-thirds of all emissions from enteric fermentation. The emissions reduction potential in Brazil, India, the U.S. and E.U. alone amounts to 350Mt CO_2e per year.

There are three main ways to reduce enteric fermentation emissions per unit of meat or milk:

1. **Improved feeding practices.** Improving the quality of forages, processing feeds to improve digestibility, and adding grain-based concentrates to livestock diets are all effective ways to improve the diet and nutrition of the animal to allow them to grow faster. These are the most promising methods of intervention globally because they tend to be low-tech, low-cost, low-risk, and provide productivity gains.
2. **Supplements and additives.** Supplements and additives reduce methane by changing the microbiology of the rumen, usually without yield improvements. They are appropriate for highly efficient systems, in which animals are in confinement for at least part of their lives, because the basal diets and nutrition regimes in these systems have already been optimized and because supplements and additives are difficult to deliver in extensive (grazing) systems. While this class of interventions has shown some potential, it is still largely in the research phase, and/or is not cost effective.
3. **Herd management and breeding.** Optimizing the health and reproductive capacity of herds can reduce the number of animals necessary to sustain a given level of production. Interventions include basic disease prevention and providing shelter for the animals, as well as high-end genetics. These interventions generally coincide with good husbandry and increased productivity. There is a great deal of room for improvement in many developing countries, particularly India.

Ultimately, the best way to reduce enteric fermentation emissions is to reduce ruminant populations (see Section 4.2 on *Shifting Diets*). When animals are held in unproductive systems, or are kept for purposes other than meat production, they are kept alive for a long time. When it takes a long time for a single animal to reach slaughter weight, not only does that animal have high emissions per unit of product, but a larger herd is needed to support a given level of production. Both feeding and herd management practices are targeted at lowering the number of animals necessary to sustain a given level of production. Because these interventions are in line with productivity gains, reductions in enteric fermentation emissions for many of the world's animal populations provide some of the most cost-effective mitigation potentials in agriculture.

The world's ruminant herds can be roughly broken into three categories, each with different mitigation opportunities.

- **Industrialized livestock production.** Most livestock production systems in highly developed countries (e.g., the U.S., E.U., Australia, New Zealand, and Canada) have already optimized the diet and nutrition of animals and already have state of the art management practices for health and reproduction. There is little that can be done to improve the productivity of these herds, under current breeding and nutrition technology. However, it may still be possible to reduce their GHG emission levels. A number of promising diet supplements and additives for ruminants may reduce the amount of methane produced in digestion. While some of these may complement the nutrition of the animal and have marginal productivity benefits, as a category, they have not been found to be successful in improving productivity, but rather specifically target methane production in the rumen. Without a sufficient productivity gain, livestock producers are unlikely to adopt these supplements and additives, at any cost, unless there are other benefits or incentives. However, in many cases, there are risks associated with supplements and additives, including potential health concerns for both the animals and human consumers. Supplements and additives hold the promise of producing ruminant meat and dairy without high levels of methane emissions. For this reason, a range of stakeholders have invested heavily into research and development in this field, including Animal Change (a collaboration funded by the E.U.), the Global Research Alliance on Agricultural Greenhouse Gases, FAO, Commonwealth Scientific and Industrial Research Organization, and the agricultural agencies of most major cattle-producing countries.
- **Medium- to low-productivity systems with large market-oriented herds.** Some of the world's largest livestock herds are managed at low productivity levels, with suboptimal diets, nutrition and herd structure. These animals take longer to reach slaughter weight (for meat animals)[1] or are less productive (for dairy animals), than animals in highly industrialized systems. Grazing herds are also often associated with land use change and deforestation, particularly in Latin America. Therefore, the emissions intensity of their output is higher (i.e., higher emissions per unit of product). Holding production levels constant, lower emissions could be achieved by improving the diets of these animals.
- **Smallholder herds.** In many parts of the world, including Sub-Saharan Africa, parts of Asia, and parts of Latin America, livestock serve multiple purposes beyond meat and dairy production. Cattle or other livestock may be raised by families and kept as financial assets or insurance mechanisms and/or for labor. While these animals may provide dairy throughout their lives and meat when they are retired, they are not raised for commodity markets. Because of their long lives as well as their poor nutrition, the meat and dairy that these animals produce have very high emissions intensities. However, reducing their emissions would require major socio-economic changes to the agricultural economies of these regions.

Co-benefits and trade-offs[2]

Co-benefits	Trade-offs
Productivity and profitability Efficiency improvements can generate productivity gains and offer a business case for farmers and livelihood benefits, especially for smallholders.	**Rebound effect** Efficiency improvements could lead to a 'rebound effect' whereby reduced production costs and higher profit margins, and/or lower consumer prices, lead to expansion of production with various negative trade-offs (e.g., deforestation).
Animal health and reproduction Addressing nutrient deficiencies improves animal health and reproduction and therefore raises overall productivity and improves animal welfare.	**GHG emissions** Some practices, such as fertilizer use or liming for improved pasture productivity can cause additional GHG emissions or other environmental impacts, such as competition with other uses of biomass.
Food security and nutritional quality Increased efficiency helps to meet rising demand for food and livestock products; particularly relevant in smallholder systems.	
Other environmental benefits Increased efficiency can have positive environmental impacts, e.g., reduced land degradation, reduced pressure on forests and other resources, and increased soil carbon stocks in pastures.	

Regional Focus

Brazil and India offer the largest regional mitigation opportunities in enteric fermentation with 105 Mt CO_2e per year of reduced emissions for improved grazing land management in pasture-based beef production in Brazil and 70 Mt CO_2e per year for improved feeding practices in dairy production from cattle and buffalo in India. If non-cattle ruminants (e.g., water buffalo, sheep, and goats), and livestock for non-dairy production are included, the mitigation potential in India nearly doubles. Benefits from reduced land use change or carbon sequestration of improved pasture management are not included in these estimates.

Brazil. Brazil has emerged as a leading supplier of global agricultural commodities. Heavy investments in research and development and the leadership of the Brazilian Cooperation for Agricultural Research (EMBRAPA) enabled the transformation of the once infertile Cerrado region into one of the most productive agricultural regions of the world. Abundant availability of land combined with large government investments into the beef industry—which led to increased horizontal concentration (the bulk of beef is processed and sold by a few companies)[3]—allowed Brazil to become the second largest beef producer in the world. Despite significant productivity gains over the last few decades, pasture-based beef production is still largely characterized by low productivity and insufficient management.

Expanding production of pasture-based beef through sustainable intensification, rather than growth through expansion of pasture area, will be vital for enhancing productivity and reducing the sector's GHG emissions. Improving the efficiency of livestock production holds important co-benefits and is well aligned with Brazil's policy priorities, namely the Low Carbon Agriculture program (*Agricultura de Baixa Emissão de Carbono*; ABC). Benefits include reduced land degradation, livelihood and economic benefits for farmers, reduced pressure on forests, land-savings for expanding cash crop production, and agricultural development. Some of these co-benefits may extend internationally (e.g., reduced pressure on resources and land elsewhere), as Brazil is the second largest beef supplier in a growing global market. Improved grazing lands management can lead to substantial productivity and profitability gains for cattle ranchers, but its adoption is impaired by obstacles, which vary by geography and type of farmer. Obstacles include lack of knowledge, cultural factors, high investment costs and associated risks, and land tenure related issues.

India. India faces a steep rise in dairy demand, yet there is a substantial gap in feed and fodder availability[4] and prices are increasing for both dairy products and feedstock. At the same time, productivity remains low, at roughly half the world average.[5] The main limitation to productivity is inadequate and insufficient feed, which typically consists of agricultural residues and seasonal pastures with poor nutritional quality. Deficiencies of essential nutrients lead to losses in productivity by affecting feed use efficiency, long-term animal health, and reproduction. Improving feeding practices by improving supply of feed and by making better use of the feed resources available (i.e., balancing of nutrients) could greatly improve emissions efficiency of the livestock sector. For example, despite its potential for substantial productivity increases and cost-savings,[6] the use of maize stover as feedstock is still uncommon. Although the productivity benefits of improved animal nutrition through improved feed are in line with the economic interests of farmers, a host of adoption barriers persist, such as lack of awareness and capacity, cultural norms, and limited access to feed markets.

In India, even marginal increases in animal productivity through improved feeding would have important livelihood and food security benefits for millions of farmers and consumers, while simultaneously decreasing the emissions intensity of livestock products. Given the food security implications of increasing milk and feedstock prices for India and the potential risk of losing its self-sufficiency in a major staple food, the country has a strong interest in increasing dairy productivity. Indian buffalo and dairy cows account for roughly 17 percent of global dairy production, most of which is consumed domestically. Smallholders, typically operating mixed crop-livestock systems with one to three buffalos or cows fed on crop residues, seasonal pastures and some additional feed, produce the majority (70 percent) of output. India has to feed 10.71 percent of the global cattle over just 2.29 percent of the global land base. Increasingly, the growing demand for food crops is creating competition for land that might be used for fodder production. Better use of available feed resources, access to better-quality stover/ other feed, and adoption of other improved feeding practices is therefore a priority.

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[1] For example, a beef cow in the U.S. takes ~16 to18 months to reach slaughter weight while a beef cow in Brazil frequently takes 30 to 36 months or more to reach slaughter weight.

[2] Improved efficiency would have very different tradeoffs in industrial systems. Here we focus on co-benefits and trade-offs of systems that currently have low-productivity,

[3] The most important slaughterhouses are Marfrig, JBS and Minerva. The main domestic retailers are Carrefour, Wal-Mart and Grupo Pão de Açucar.

[4] The supply gap is 40 percent, 36 percent and 57 percent in dry fodder, green fodder and concentrates, respectively. Department of Animal Husbandry, Dairying & Fisheries. (2013). *Annual Report 2012-13.* New Delhi, India: Ministry of Agriculture, Government of India.

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3.4
SEQUESTERING CARBON IN AGRICULTURAL SYSTEMS

Background

Soils hold an enormous amount of carbon. As much as 1,500 Gt of soil organic carbon (C) is stored to a depth of one meter, [1] versus roughly 270 Gt C stored in standing forest stocks globally.[2] There are numerous land and crop management practices that can increase the soil organic carbon in agricultural soils. Agricultural carbon stocks can also be built through in-ground biomass. These practices break down into three main categories:

1. **Management of soil carbon in cropping systems.** There are two main ways to increase carbon stocks in cropland soils: 1) to protect existing carbon in the system by slowing decomposition of organic matter and reducing erosion, and 2) to increase the amount of carbon in the system. A primary method for the first approach is to reduce the frequency with which the soils are tilled (reduced tillage, or no tillage[3]). Soil carbon can also be protected through practices that control erosion, such as terracing, contour strips and cover crops. The most common method for the second approach is simply to retain crop residues on the croplands. Other options include increasing the use of perennials (which have larger root systems than annuals), applying biochar[4], and even increasing the use of fertilizers in system with little or no fertilizer use.[5] This set of practices is often referred to as "conservation agriculture".
2. **Agroforestry.** Agroforestry is an intensive land management system that combines above-ground biomass (e.g., trees or shrubs) with crops and/or livestock. Agroforestry systems can include everything from windbreaks and riparian buffers to silvopasture (trees planted on grazing land) and forest farming. These systems have a long tradition in temperate regions around the world, and have also been developed as a land management practice in many developing countries, particularly for smallholder systems.[6]
3. **Improve carbon storage in grazing lands.** Carbon stores in grazing lands can be protected and increased through a variety of measures that promote productivity of grasses. Improved pasture management practices include managing stocking rates, timing and rotation of livestock, introduction of grass species or legumes with higher productivity, and application of biochar, compost, fertilizer, or irrigation to increase productivity. All of these practices can increase soil carbon storage.[7] The opportunity for additional carbon sequestration in grazing lands is equal to the difference between the levels of soil organic matter currently in the land and what is possible for the system given soil type and climate. Carbon accrual on optimally grazed lands is often greater than on ungrazed or overgrazed lands.[8] However, the effects are inconsistent due to the many types of grazing practices employed and the diversity of plant species, soils, and climates involved.

The potential to build carbon stocks in agricultural soils and aboveground biomass has been a focus of conservationists in the agricultural community for decades. Though there is clearly a significant technical opportunity for carbon sequestration, it is also clear that it is not a panacea. The agricultural chapter of the 2007 IPCC 4th Assessment Report attributed roughly 90 percent of the total technical GHG mitigation potential in the agricultural section to carbon sequestration (~5,000 Mt Co_2e per year).[9] However, the scientific literature has become less optimistic in recent years. Review papers conclude that there is great inconsistency in observed carbon sequestration rates from different management practices, primarily due to difference in soil type, topography, biomass material, climate, and management practices.[10] There is particular controversy around the carbon sequestration impacts of tillage practices.[11] Critics of the IPCC 4th Assessment Report note that the sequestration potential of soils clearly limited by the availability of carbon sources, particularly in low-yielding systems and in places where there are competing demands for these residues.[12]

There is a justified concern from a sizable segment of the scientific community that an over-emphasis on the benefits of soil carbon sequestration may detract from other measures in the agricultural sector which are at least as effective in combating climate change.[13] However, maintaining soil organic matter is vital for farmers everywhere, regardless of the potential to measure soil carbon sequestration. Most practices that increase the carbon content in agricultural soils are good agricultural practices anyway and lead to increased yields. Considering the need to intensify agricultural production, an active consideration of increasing soil carbon within existing agricultural programs requires comparatively little effort with potential significant benefits.

Co-Benefits and trade-offs

Co-benefits	Trade-offs
Food Security Increasing the soil organic matter of soils improves the soil fertility, reduces erosion, increases moisture retention and can lead to increased yields.	**Competing Uses for Biomass** Sources of biomass that could be used to increase soil organic matter (e.g., crop residues and manure) often have competing uses including household fuel for smallholders and livestock fodder.
Climate Resilience Increased levels of soil organic matter can help make agricultural soils resilient to the stresses from climate change. In particular, the moisture retention properties of soils with higher carbon content can help agricultural lands remain productive as climates become drier.	**Displacement** Certain practices (e.g., increased use of perennials) can displace primary crops, thus lowering their yields and potentially causing indirect land use change.
	Uncertainties and MRV Challenges There are no cost-effective means of accurately measuring soil carbon stocks and changes in stocks over time.
	Reversibility Even when carbon has been sequestrated, there is no guarantee that it will stay in the soil.

Regional Focus

Opportunities to improve the management of carbon in agricultural systems can be found across the globe and in almost any agricultural system. The technical potential for any given hectare to increase its carbon stocks depends on the soil type, climate, available sources of biomass, and technical potential to change management practices. A comprehensive, spatially explicit, global assessment of the technical potential for agricultural carbon sequestration since the IPCC 4th Assessment Report does not exist.[14] A handful of regional modeling efforts have helped determine the technical potential of soil carbon sequestration on both croplands and grazing lands in a few countries or regions, based on the adoption of no- or reduced-tillage or crop residue management practices (see Table 2 and 4 in Annex 3).

Given the data limitations, it is difficult to identify with confidence either the most promising geographies or a sense of relative mitigation potential compared with other recommendations in this report. Our recommendations are therefore more informed by the identification of synergies with other policy priorities and existing programs rather than a quantitative assessment of mitigation potential.

One way to prioritize support for increased soil carbon sequestration in agricultural systems geographically is to identify those places where soil carbon content in agricultural soils is particularly low and where the links to food security and poverty reduction are strongest. Sub-Saharan Africa is a prime example of such a location.

In **Sub-Saharan Africa**, where smallholders are particularly vulnerable to the impacts of climate change and long term investments in soil fertility is critical for food security, particular attention to soil carbon is imperative. Billions of dollars in agricultural development investments flow through this region annually. The majority of these investments are made without consideration for their impact on GHG emissions or adaptation to climate change. Ensuring that the organizations (e.g., multi- and bi-lateral financial institutions, national governments, philanthropic foundations, private sector, farmer associations, and NGOs) investing in agricultural development in Africa are integrating a focus on soil carbon content into their work is an important step for African food security and agriculture climate change mitigation alike.

Currently, development and implementation of soil carbon management strategies in Sub-Saharan Africa are severely hampered by a lack of data on soil types, soil carbon contents and fluxes. Despite a number of promising pilots,[15] data on soil organic matter in African soils remains scarce and there are almost no data describing how the soil carbon content changes over longer periods. Long-term data series on soil type, carbon contents, and fluxes in different soils are essential to making policy and prioritizing investments, and improvements in data will support better integration of carbon and climate into the agricultural agenda across Sub-Saharan Africa.

In addition, almost any country with large tracts of grazing land is likely to have opportunities to increase carbon sequestration on these lands. The majority of the world's overgrazed lands are in Africa and Eurasia.[16] Very degraded land is expensive to restore. However, lightly degraded lands can be restored at low costs and can provide substantial gains in soil carbon. Geographic prioritization should be placed on countries that have large areas of grazing land that are important to their agricultural economies (e.g., Brazil, China, Mongolia, Kenya, and Ethiopia). Further, those countries that already manage much of their grazing lands and that are already investing in them should be a high priority. Brazil is a prime example.

In **Brazil**, we recommend integrating silvopastoral systems as well as increasing the quality of the forage on grazing land. Both of these interventions can help lead to increased stocking rates and carbon sequestration. Increasing the productivity of grazing lands in Brazil has the potential to help reduce emissions from deforestation.

Lastly, supporting the development of biochar as an effective mechanism for soil carbon sequestration is a worthwhile initiative. Biochar provides an excellent use of agricultural biomass from a mitigation perspective because it sequesters carbon in the soil for long periods. At the same time, the yield benefits, costs, applicability, and mitigation potential of biochar are highly variable and biochar production continues to face technical challenges. However, because the mitigation potential of biochar is significant, we believe that the technology, field, and markets warrant development.

Market development may be most viable and most beneficial from a mitigation perspective in places where the feedstock is currently a detriment. A good example is rice straw burning in **China and other parts of Asia**. Even though rice straw burning is now banned in China, it is still a common practice, to the detriment of both human health and GHG emissions.[17] Bamboo is also a potential feedstock for biochar in China and may be gaining traction, although it provides fewer environmental co-benefits than rice. The China National Bamboo Research Center has developed a biochar/fertilizer pellet which has been approved by the Environmental Ministry. **Brazil** is another country which could be a good early adopter of large scale biochar production. Brazil has a very sophisticated charcoal production

industry which could be fairly easily repurposed to produce high-quality biochar, given the right incentives. Biochar application on Brazil's crop and grazing lands could help sustain soil fertility and productivity, potentially reducing pressure of forest lands.

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[1] Powlson, D., Whitmore, A., Goulding, K. (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science,* 42–55.

[2] Food and Agriculture Organization of the United Nations. (2010). *Global Forest Resources Assessment 2010*. Rome, Italy: Food and Agriculture Organization of the United Nations.

[3] Though the term "no tillage" is used commonly, it is rare for farmers to eliminate tillage completely. Often, some event(s) such as drought, compaction, or pests can require a tillage event every few years or so, even in "no-tillage" systems.

[4] Biochar is a solid output of the thermal decomposition (pyrolysis) of plant matter. It can be plowed into soils and can store carbon in a fairly stable form for up to several hundred years, depending on the quality of the feedstock and the pyrolysis process.

[5] In agricultural systems with low yields and low fertilizer inputs, increasing the use of fertilizer can increase yields and thus increase crop residues. More residues leads to more carbon that can be returned to the soils to increase soil organic matter. However, additional fertilizer use can lead to increase nitrous oxide emissions, so the net benefits should be evaluated on a case by case basis. Source: Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P. (2013). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems and Environment.*

[6] van Vark, C. (2013)."How agroforestry systems can improve food security in developing countries. *The Guardian.*

[7] Schnabel, R., Franzluebbers, A., Stout, W., Sanderson, M., Stuedemann, J. (2001). The effects of pasture management practices. *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, Follett R.F., Kimble JM., and Lal R. (Eds) 291-322.; Conant, R. Paustian, K., Elliot, E. (2001). Grassland management and conversion into grassland: Effects on soil carbon. *Ecological Applications, 11,* 343-355.

[8] Liebig, M., Morgan, J., Reeder, J., Ellert, B., Gollany, H., Schuman, G. (2005). Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. *Soil & Tillage Research*, 83.; Rice, C., and Owensby, C. "Effects of fire and grazing on soil carbon in rangelands." *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, Follett R.F., Kimble JM., and Lal R. (Eds). 323-342.

[9] 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. I*n 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, United Kingdom: Cambridge University Press.

[10] Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P. (2013). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems and Environment*.

[11] There seems to be general consensus that adoption of reduced-tillage or no-tillage management practices increases soil carbon stocks within the top ten centimeters of soil. However, there is debate as to the impacts of tillage on carbon at deeper depths, with some studies indicating that if a deeper soil column is considered, carbon sequestration does not increase as a result of tillage practices. Source: Palm, C. et al. (2013).

[12] Giller, K., Witter, E., Corbeels, M., Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research, 114*, 23-24; and Palm, C. et al. (2013). See fn #10

[13] Powlson, D., Whitmore, A., Goulding, K. (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science, 62,* 42–55.

[14] Very little has been published since then to help answer this question, with the important exception of a 2010 assessment of the global mitigation potential of biochar. Woolf, D., Amonette, J., Street-Perrott, F.A., Lehmann, J., Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications, 1. 56*

[15] A number of projects, for example the Africa Soil Information Service, are working to shed light on soil health, soil carbon content, and appropriate measurement systems. Other projects, such as the Kenya Agricultural Carbon Project, explore the institutional, economic and social barriers to better soil carbon management.

[16] Conant, R. and Paustian, K. (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biochemical Cycles,16*.

[17] However, it is important to realize that rice hulls contain silica, which can produce a carcinogenic product if rice-based biochar is produced improperly (at high temperatures). Care needs to be taken to ensure high quality production.

3.5

REDUCING METHANE EMISSIONS FROM RICE CULTIVATION

Background

Rice is one of the most important cereal crops in the world, grown on more than 140 million hectares and consumed more than any other staple food.[1] Close to 90 percent of rice is grown in Asia, and of that, 90 percent is grown in flooded or partially flooded paddy fields.[2] When fields are flooded, the decomposition of material depletes oxygen in the soil and water, causing anaerobic conditions that generate methane. The water management system of rice cultivation is therefore one of the most important factors affecting and causing GHG emissions. Other factors, including soil type, tillage management, residues, and fertilizer, also play a role. Methane emissions from rice production account for 11 percent of GHG emissions from the agricultural sector and a third of emissions from crops in 2010,[3] making it the crop with the highest GHG footprint. Nitrous oxide emissions from fertilizers applied to rice would increase this percentage. In addition, rice uses about 40 percent of the world's irrigation water and 30 percent of the world's developed freshwater resources.[4]

The management of rice production features four particular techniques that can contribute significantly to mitigation:

1. **Improved water management.** Water-saving techniques in irrigated rice production limit the duration of standing water in the fields, thereby suppressing anaerobic decomposition. Reduced standing water conditions can be achieved through mid-season and multiple drainages, alternate wetting and drying as well as shifting from flooded to merely moist soils. Mid-season drainage involves the removal of surface water from the crop towards the end of tillering for about seven days, or long enough to observe indicators of dry conditions in the field (e.g., small soil cracks). In contrast, alternate wetting and drying encompasses a series of non-flooded intervals throughout the growing season (with the exception of the sensitive flowering stage of the rice plant). These practices aerate the soil and thus interfere with anaerobic conditions, achieving methane emission reductions ranging from 7–95 percent.[5] Out of these water management methods, alternate wetting and drying can be seen as the most attractive mitigation option because of the incentives to farmers stemming from water saving. Many rice farmers use pumps for enhancing irrigation capacities, so that water saving translates into lower energy costs (and lower fuel consumption) in cases when gravity-driven water supply becomes insufficient or when farmers fully rely on groundwater irrigation sources. Due to improved crop management aiming at higher resource-use efficiencies, acute water shortages and new forms of mechanization such as dry-seeding and combined harvests that require drier soils to drive on, a trend towards increased drying and draining of fields has been seen in many rice growing countries.

   It should be noted that rice—just as any other fertilized crop—is also a significant anthropogenic source of nitrous oxide (N_2O). Reduced water use creates unsaturated soil conditions, which in turn may cause N_2O production once the soil is flooded again. Therefore, the reductions in methane emissions from drainage/ drying methods may be slightly offset by an increase in N_2O emissions, with some studies citing approximately 15–20 percent of the benefit gained being offset.[6] However, nitrous oxide emissions can be kept at low levels through appropriate fertilizer management that matches nitrogen supply with the actual uptake by the plant (see Section 3.2 on *Fertilizer Management*).[7]

Achieving optimal water levels throughout the season requires precise control of water, so this intervention can only be applied to irrigated systems and requires technical knowledge.

2. **Improved rice straw management.** After water management, changes in rice straw residue management present the highest GHG mitigation potential. At present, most rice straw residues are burned or incorporated into the soil during flooding. Farmers consider these practices to be convenient and cost-effective; however both generate significant GHG emissions. Alternative practices to reduce GHG emissions include off-season application (under dry soil conditions), composting, and turning rice straw into biochar followed by application. Biochar is one of the most effective ways to solve the problem of unused crop residues, and is outlined in Section 3.5 on *Carbon Sequestration.*
3. **More precise nutrient management.** More precise nutrient management would decrease methane and nitrous oxide emissions from fertilizer use and production. Nutrient management techniques and recommendations are outlined in Section 3.2 on *Fertilizer Management.*
4. **Other changes in farming practices.** Other strategies include the use of crop rotations, higher yielding varieties and no tillage practices, all of which help to reduce the GHG footprint per unit of output. Given the popular shift towards drainage and drying of rice cropping systems, these practices have the potential for substantial GHG emission reductions in the future. There is currently a lot of work going on to design such future systems and optimize their management.

Co-benefits and trade-offs

Co-benefits	Trade-offs
Increased productivity and resilience Well managed rice fields (water, residues, nutrients, rotations, etc.) can increase productivity and yields long term. They are also more resilient to climate change impacts including droughts and floods.	High capacity needs Correct management of water levels requires a very precise control of water, which can only be done in irrigated systems and requires knowledge on the specifics of the respective technique. Similar capacities are needed for nutrient management. High technical capacity needs may present barriers to adoption.
Cost savings Water management reduces costs of water and fuel for irrigation pumps, particularly relevant where water is scarce and expensive. Nutrient management also reduces capital costs of fertilizer use.	Potentially reduced yields and delayed harvest Incorrectly managed water levels may reduce yields. Drainage may also delay crop development, and thus harvest by approximately 7–10 days.
Increased water quantity and quality A significant amount of water is conserved through water management practices. Additionally, water quality can be improved where fertilizer use is reduced.	Not applicable to terraced fields Intermittent drying or soil drainage is not feasible on terraced rice fields because drying may cause water losses from soil cracking, or in extreme cases, a collapse of the terraced construction.[8]
Enhanced health conditions Avoiding the burning of rice straw residues significantly improves air quality and has long-term positive implications for health conditions.	

Regional Focus

Asia is the main region where rice is produced globally (90 percent) and therefore represents the main opportunity for interventions. The top rice producing countries—China, India, Indonesia, Bangladesh, Vietnam, and Thailand—account for more than 75 percent of global rice production.[9] Southeast Asia and China provide a combined technical mitigation potential of 120 Mt CO_2e per year from rice.[10] For water management interventions, it makes sense to focus on countries with high percentages of irrigated rice production, as it requires systems in which water levels can be well controlled. The percentage of irrigated rice fields varies widely in Asian countries:

- Greater than 75 percent irrigated: Pakistan, Sri Lanka, Vietnam, China, Taiwan, Japan, South Korea
- 60 to 75 percent irrigated: Bangladesh, Indonesia, Philippines, Malaysia, North Korea
- Less than 60 percent irrigated: India, Thailand

ASEAN. Given that the specific mitigation gains of individual countries are relatively small (with the exception of China), it is recommended that a regional approach be taken that establishes a model which is then scaled up and applied across multiple countries. While the practices that need to be employed vary between farming systems, a regional approach can effectively respond to local conditions and leverage country-specific financial tools. The Association of Southeast Asian Nations (ASEAN), a political and economic organization of ten countries,[11] includes many key rice producing nations, and thus offers substantial mitigation potential. ASEAN also presents a good platform for addressing the economic and food security issues related to climate change and rice production.

Rice is vital for food security as well as employment throughout Asia, but the ASEAN group of Southeast Asian countries can be seen as the most promising regional entity for mitigation in rice production at this point. Given the crop's vulnerabilities to climate change impacts, there is broad consensus among ASEAN members on the urgency to adapt rice farming systems to climate impacts. In principle, mitigation of GHG emissions is a distinct objective, but the various programs and projects that already focus on increasing resilience and productivity can be seen as good entry points to scale up mitigation. In view of the high contribution of rice production within the national GHG budgets of Southeast Asian countries, ASEAN has already committed, through frameworks and initiatives, to act as a community to address these adaptation and mitigation issues together, however progress is limited on the ground. With the right tools and incentives, ASEAN provides an excellent platform for scaling up successful pilots that sustainably intensifies rice production, increases resilience and incorporates mitigation.

China. As the largest rice producer in the world, China presents significant mitigation potential with rice methane emissions at roughly 110 Mt CO_2e in 2005.[12] However, mid-season drainage and other water-saving rice irrigation techniques are now the common practice on most rice fields and the burning of rice straw residue has been banned across the country.[13] Additional interventions are therefore best directed towards improved nutrient management and zero-tillage.[14]

Vietnam. Among the ASEAN members, Vietnam represents the most promising country for mitigating emissions through water management which can be attributed to the high percentage of irrigated rice production systems (89 percent) at national scale. Alternate wetting and drying has gained momentum and is considered an important mitigation measure in Vietnam's national program. The program has shown the potential to give direct monetary benefits to farmers in areas where pumps are used. Straw management has also come into focus recently with higher levels of mechanization and the increasing value of straw. Given these developments and its membership in ASEAN, Vietnam may be a good role model for early implementation and piloting.

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[1] Wassmann, R., Hosen, Y., Sumfleth, K. (2009). *Agriculture and Climate Change: Reducing Methane Emissions from Irrigated Rice.* Washington, D.C.: 2020 Vision for Food, Agriculture, and the Environment.

[2] Ibid.

[3] Food and Agriculture Organization of the United Nations. (2013). FAOSTAT. Retrieved 2013-14, from http://faostat.fao.org.

[4] International Rice Research Institute (IRRI). Retrieved 2013-14, from http://www.irri.org/index.php?option=com_k2&view=item&id=9151&Itemid=100480&lang=en

[5] Uprety, D.C., Dhar, S., Hongmin, D., Kimball, B., Garg, A., Upadhyay, J. (2012). *Technologies for Climate Change Mitigation: Agricultural sector.* Denmark: UNEP Risø Centre on Energy, Climate and Sustainable Development.

[6] Zou, J., Y. Huang, J. Jiang, X. Zheng, and R. L. Sass. (2005). A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China: Effects of water regime, crop residue, and fertilizer application. *Global Biogeochemical Cycles, 19*.

[7] Wassmann R., K. Butterbach-Bahl, A. Dobermann. (2007). Irrigated rice production systems and greenhouse gas emissions: crop and residue management trends, climate change impacts and mitigation strategies. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources.*

[8] Uprety, D.C. et al. (2012). See fn #5

[9] International Rice Research Institute (IRRI). Retrieved 2013-14, from http://www.irri.org/index.php?option=com_k2&view=item&id=9151&Itemid=100480&lang=en

[10] CEA estimate. See Annex 3 for further details.

[11] Current ASEAN countries include: Indonesia, Philippines, Malaysia, Singapore, Thailand, Vietnam, Cambodia, Laos, Myanmar and Brunei (with Timor Leste and Papua New Guinea having observer status)

[12] Food and Agriculture Organization of the United Nations. (2013). FAOSTAT. Retrieved 2013-14, from www.faostat.fao.org.

[13] Zou, J. et al. (2005). See fn #6

[14] Feng, J., Chen, C., Zhang, Y., Song, Z., Deng, A., Zheng, C., and Zhang, W. (2013). Impacts of cropping practices on yield-scaled greenhouse gas emissions from rice fields in China: A meta-analysis. *Agriculture, Ecosystems and Environment, 164,* 220-228.

3.6 MANAGING MANURE

Background

Livestock manure and urine account for roughly one quarter of direct agricultural GHG emissions. About 16 percent of these emissions are caused by manure deposited on pastures and seven percent are from stored manure. An additional two percent of agricultural emissions are caused by manure applied as fertilizer to croplands (see Section 3.2. on *Fertilizer Management and Production*).[1] Manure and urine can cause both nitrous oxide and methane emissions. They cause nitrous oxide emissions when deposited on pastures by grazing animals, used as a fertilizer on croplands, or stored in dry agricultural systems. Manure and urine stored in wet (anaerobic) systems create methane emissions. Although mitigation options exist for manure on pasture, they are often very difficult to implement because of the dispersed nature of the deposits. Thus, this report focuses exclusively on manure in stored systems. Although stored manure accounts for a relatively small amount of direct agricultural emissions, it is technically possible to mitigate a very high percentage of these emissions (as much as 70 percent for most systems).[2] We project that by 2030, the global technical mitigation potential will be roughly 260 Mt CO_2e per year compared with a baseline.

Approximately half of the manure in stored systems is from monogastrics (primarily pigs and chickens), and another 20 percent is from dairy cattle. Although beef cattle account for nearly half of all livestock emissions, they contribute less than 20 percent of stored manure emissions because they typically spend so much of their lives grazing.[3]

Although manure can be a productive source of nutrients for crops and grazing lands, when livestock production systems become industrialized and heavily concentrated geographically, there is not enough land to absorb the resulting volume of manure. These nutrients often instead become a source of water and air pollution, as well as a source of GHG emissions. Although one of the leading mitigation opportunities for stored manure is anaerobic digestion, which is both high-tech and high cost, there are quite a few simple storage and handling practices that can reduce emissions and are low-tech and low-cost. Further, improved manure management practices tend to have very important co-benefits. There are three primary approaches to emissions reduction for stored manure:[4]

1. **More efficient use of manure as an energy or crop nutrient source.** If designed properly, better management of manure can reduce the need for synthetic fertilizers, displace fossil fuels, create profitable products for producers, and increase the productivity of croplands and pastures.

    - One of the most popular mitigation practices for stored manure is methane, or anaerobic, digesters. Digesters can turn the methane from manure slurry into either electricity or natural gas, for use on-site or for sale to local utilities. Methane digesters are costly and as a general rule are not economically efficient for producers unless there are policies in place to create sufficient incentives (e.g., guaranteed pricing for bioenergy from utilities or direct subsidies). Using manure for bioenergy has the added benefit of off-setting fossil fuels, although this report does not quantify the additional mitigation benefit of these offsets.

    - Turning manure into compost can potentially provide a relatively stable carbon source as well as valuable nutrients when applied on land. If compost can be sold as a value-added product (particularly to high-end agricultural markets, such as nurseries), it could prove to be economical for producers. The cost of transporting compost may be a limiting factor, as well as regulations regarding the processing requirements for compost.

- Better timing and application of manure directly to agricultural lands can be greatly aided by regional planning. If the right policies are in place, better use of manure can reduce the need for synthetic fertilizer, reduce emissions, reduce nutrient loading into ground and surface water bodies, and increase the productivity of croplands and pastures.

2. **Storage and handling practices.** Emissions from stored manure can be greatly reduced through a number of simple storage and handling practices. Such practices include reducing storage time (if not being digested for energy generation), covering the manure, avoiding straw/hay bedding (i.e., removing additional sources of carbon which add to methane emissions when decomposed in anaerobic conditions), and using housing and waste management systems that enable better handling of manure. Though these practices are typically low-cost and low-tech, they often require more time and effort on the part of the producer. Thus, because they do not provide productivity gains, these practices may still need to be supported by policy incentives.
3. **Diet changes.** Changing the diet of livestock can affect the volume and composition of manure, helping to reduce the emissions. Practices include balancing dietary proteins, tannin supplements, and other feed additives. Reduced protein intake reduces nitrogen excreted by animals, and supplements (such as tannins) can shift nitrogen excretion from urine to feces to produce a net reduction in emissions. Balancing dietary proteins is a reliable strategy, but more research is needed on the efficacy of other feed additives. Here again, these practices may need to be supported by policy incentives since they do not provide significant economic benefits to farmers.
4. **Shift to diversified farming systems:** Although this section focuses on stored manure, it is clear that moderately-sized, diversified farming systems which integrate crops and livestock are more effective at using nutrients from manure. If well-managed, manure can provide a valuable farm resource that increases overall farm productivity and reduces the need for synthetic nitrogen fertilizer.

Co-benefits and trade-offs

Co-benefits	Trade-offs
Reduced environmental degradation Improved manure management reduces ground and surface water pollution as well as air pollution (ammonia and particulate matter).	Interventions can be costly Costs for mitigation are not offset by an increase in productivity because manure is a byproduct of livestock production. Thus markets for value-added products (e.g., electricity, fuel, fertilizer), or other financial incentives, are needed.
Health improvements Improved manure management often reduces odor, and can even benefit human and animal health by reducing the risk of pathogen transfer.	Labor and technology requirements High labor needs, access to technologies, and technical knowledge present barriers to adoption.
Source of energy Manure can become a source of bioenergy (i.e., to displace fossil fuels either as a source of electricity, biogas, or transportation fuel)	
Source of fertilizer Manure provides a source of nutrients that can displace synthetic fertilizers.	

In many parts of the world, manure management has improved simply as a result of basic environmental regulations (e.g. U.S. Clean Water Act, E.U. Water Framework Directive). Certainly in many developing countries, there is considerable room for increased regulation of manure management, and the imperative for doing so may become dire in some places as industrialized meat production expands. Because there are ways to transform manure into value-added products (e.g., electricity, fuel, fertilizer), and because there are so many environmental and health benefits of doing so, regulations and financial incentives that provide profitable avenues for farmers to enter these markets may be in the best interest of policy makers.

Regional Focus

Priority countries and geographies for action include China and the U.S., Europe, and India. Mitigation potentials reflect the annual opportunity by 2030, compared with a baseline.

China. The opportunity for reducing emissions from stored manure is significant in China (45 Mt CO_2e per year), where manure management practices have not yet been widely implemented in concentrated feeding operations (although digesters are becoming more common thanks to government subsidies), water protection regulation is weak, and massive growth is anticipated in confined pig and poultry populations. China has the fastest growing industrial livestock production sector of any country in the world. Roughly 3,000 million tonnes of livestock manure was generated in 2010 by China's livestock. And an additional 1,000 million tonnes per year is expected to be generated by 2030.[5] Any effort to address improved manure management should consider engaging in China.

Given that animal production is industrializing so quickly, there is a great opportunity to preempt over-saturation of manure application on surrounding croplands by conducting spatial planning for concentrated feeding operations as they are being developed. Further, China has a serious problem with overuse of nitrogen fertilizers; thus, more efficient and accountable use of manure could help reduce nitrogen fertilization overall.

U.S. In contrast to Europe, the U.S. has been slow to adopt methane digesters, and thus, the technical emissions reduction potential in the U.S., roughly 40 Mt CO_2e per year, may be available at lower costs than the remaining emissions reduction potential in Europe. A number of NGOs, industry associations, academic institutions, and a few progressive regional regulatory bodies have continued to experiment and explore viable solutions to the manure problem in the U.S., despite a broadly unfavorable regulatory climate. Support for these kinds of innovative partnerships and integrated solutions is worthwhile.

Europe. Europe has been a leader in the sustainable management of stored manure with a number of policies driving the adoption of methane digesters. Even though the region still has the technical potential to reduce emissions from stored manure (45 Mt CO_2e per year), it is likely that the "low hanging fruit" has been harvested and that further mitigation will be costly. The fact that sizable mitigation potential still remains is likely just a reflection of the very large livestock populations in stored systems across the region. Distilling lessons from Europe for potential replication elsewhere may be helpful.

India. Although most of India's livestock sector is not raised in industrial, confined systems, that may change in the coming years given the growth in India's dairy sector. As India shifts towards industrialized dairy production, there may be a good opportunity to ensure that effective manure management systems are included at the onset. The current technical mitigation potential is modest at roughly 20 Mt CO_2e per year.

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[1] Food and Agriculture Organization of the United Nations. (2013). FAOSTAT. Retrieved 2013-2014, from http://faostat.fao.org.

[2] Hristov, A., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkinds, J., Rotz, A., Dell, C., Adesogan, A., Yang, W., Tricarico, J., Kebreab, E., Waghorn, G., Oosting, S. (2013). *Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO_2 emissions.* Rome, Italy: Food and Agriculture Organization of the United Nations Animal Production and Health.

[3] Food and Agriculture Organization of the United Nations. (2013). FAOSTAT. Retrieved 2013-2014, from http://faostat.fao.org.

[4] Primary sources for these interventions are: i) Hristov, A., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkinds, J., Rotz, A., Dell, C., Adesogan, A., Yang, W., Tricarico, J., Kebreab, E., Waghorn, G., Oosting, S. (2013). M*itigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO_2 emissions.* Rome, Italy: Food and Agriculture Organization of the United Nations Animal Production and Health; ii) Gerber, P., Hristov, A., Henderson, B., Makkar, H., 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., Oostring, S. (2013). Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review. *Animal*.; iii) Petersen, S., Blanchard, M., Chadwick, D., del Prado, A., Edouard, N., Mosquera, J., Sommer, S. (2013). Manure management for greenhouse gas mitigation. *Animal*, 266-282.; iv) Archibeque, S., Haugen-Kozyra, K., Johnson, K., Kebreab, E., Powers-Schilling, W., Olander, L., Van de Bogert, A. (2012). *Near-Term Options for Reducing Greenhouse Gas Emissions from Livestock Systems in the United States.* Washington, D.C.: Technical Working Group on Agricultural Greenhouse Gases. v) Additional information can be found in the supplementary materials available at www.agriculturalmitigation.org.

[5] Chadwick, D., Qing, C., Yan'an, T., Guanghui, Y., Qirong, S. (2012). *Improving manure nutrient management towards sustainable intensification in China.* UK-China Sustainable Agriculture Innovation Network (SAIN).

4.

DEMAND-SIDE STRATEGIES

The discussion on food security and agriculture mitigation over the last two decades has almost exclusively focused on ways to increase productivity and reduce net GHGs emissions from production. However, as the global population grows and incomes rise, we will also need to pay attention to the demand-side of the equation, including which products we consume, how much we consume, and how much food we waste. Major demand shifts have the technical potential to reduce overall emissions associated with agriculture by roughly 55 percent by 2030, compared with a baseline. Although the potential to reduce the GHG footprint of the agricultural sector through changes to consumption patterns is enormous, the certainty around the mitigation estimates is very poor and the literature on this topic is only beginning to emerge.

4.1

REDUCING FOOD WASTAGE

Background

According to FAO estimates, approximately one third of all food intended for human consumption is lost or wasted in the value chain (production, handling and storage, processing and packaging, distribution and market, and consumption).[1] Food loss happens before it reaches the consumer through spoilage, spilling or other unintended consequences due to limitations in agricultural infrastructure, storage and packaging. Food waste refers to food that is intentionally discarded, usually during distribution (retail and food service) and consumption. 'Food wastage' in this report refers to both food loss and waste. The carbon footprint of food wastage is estimated at 3.3 Gt CO_2e, making it the third largest source of emissions after China and the U.S.[2]

More than half (54 percent) of food wastage occurs during 'upstream' practices of production, post-harvest handling and storage, while 46 percent of it is attributed to 'downstream', at the processing, distribution and consumption stages.[3] Cereals comprise the greatest share of losses by calorie and emissions (53 percent and 34 percent, respectively), while fruits and vegetables comprise the greatest share of losses by weight (44 percent) and the second greatest share of emissions (21 percent).[4]Although meat wastage is responsible for a relatively low percentage of losses by calorie and weight (7 percent and 4 percent), it accounts for a high percent of carbon emissions, equivalent to fruits and vegetables (21 percent).

In the developing world, losses mainly occur postharvest as a result of financial and technical limitations in production techniques, storage and transport. In contrast, losses in the developed world are mostly incurred by end consumers. Consumer behavior and high expectations of food aesthetics and availability are the main contributors to the high levels of food waste in developed countries. A World Resources Institute (WRI) study shows how some of these drivers of food wastage may be addressed through the following approaches (Figure 13) in the value chain:

Figure 13. Possible approaches for reducing food wastage along the supply chain[5]

PRODUCTION	HANDLING AND STORAGE	PROCESSING AND PACKAGING	DISTRIBUTION AND MARKET	CONSUMPTION
Facilitate donation of unmarketable crops	Improve access to low-cost handling and storage technologies (e.g. evaporative coolers, storage bags, metal silos, crates)	Re-engineer manufacturing processes	Faciliitate increased donation of unsold goods	Facilitate increased donation of unsold goods from restaurants and caterers
Improve availability of agricultural extension services.	Improve ethylene and microbial management of food in storage	Improve supply chain management.	Change food date labeling practices	Conduct consumer education campaigns
Improve market access	Introduce low-carbon refrigeration	Improve packaging to keep food fresher for longer	Change in-store promotions	Reduce portion sizes
Improve harvesting techniques	Improve infrastructure (e.g. roads)		Provide guidance on food storage and preparation to consumers Improve inventory systems	Ensure home economics taught in schools, colleges, and communities

Source: Lipinski et al., 2013.

Simplistically calculated, cutting current food wastage levels in half has the potential to close the 70 percent gap of food needed to meet 2050 demand by roughly 22 percent,[6] potentially making the reduction of food wastage a leading strategy in achieving global food security. As food wastage is a byproduct of inefficiency, the negative trade-offs are limited and there are vast opportunities for savings along the entire supply chain. While the extent of food wastage has been well documented in recent years,[7] mitigation potential has not been comprehensively studied. However, assuming that a 3 percent or more decrease in food wastage by 2030 causes a 3 percent decrease in crop and grazing land area, the resulting carbon sink and displaced fossil fuel emissions have the potential to mitigate 0.38 to 2.1 Gt compared to a baseline scenario.[8] The mitigation potential of avoided livestock emissions and avoided energy and transportation costs along the supply chain is not included in this total. In many postharvest and end-consumer conditions, a reduction of at least 50 percent in food wastage is feasible. A recent study by Parfitt et al. 2010 (referenced in Smith et al. 2013) reports that in the UK, 64 percent of food wastage is "avoidable." Addressing food loss and waste along global agricultural value chains stands out as a 'win-win' strategy for its potential to reduce GHG emissions substantially more than most agriculture mitigation strategies, increase food availability and reduce pressure on ecosystems and natural resources.

Co-benefits and trade-offs

Synergies and Co-Benefits	Trade-offs and Risks
Conserved natural resources Reducing wastage can conserve significant amounts of water and land, which can be repurposed for other uses, as well as reduce the need for expansion.[9]	**Potentially reduced profits** There is a risk of potential short-term profit shortfalls in the supply chain due to some decreased demand in developed countries, particularly with retailers.
Cost savings More efficient management of food can reduce direct economic costs to farmers and consumers, currently estimated at USD 750billion,[10] as well as indirect costs of water and land.	
Increased food security Reducing food loss and waste can increase food availability and access by increasing local supplies and freeing available resources.	

Regional focus

Asia makes up approximately 51 percent of the global share of total food loss and waste by calorie (kcal), followed by North America and Oceania (Canada, U.S., Australia, New Zealand) with 14 percent, and Europe with 14 percent (see Figure 14). On a per capita basis, South/ Southeast Asia is the region with the lowest food wastage per capita while North America and Oceania is the highest, wasting about 1,500 kcal per person per day from farm to fork (vs. 748 for Europe, the next most wasteful region).

From a GHG emissions perspective, cereals in industrialized Asia have the highest carbon footprint from total food wastage, followed by South/ Southeast Asia.[11] The problem is particularly acute with rice given its high methane emissions, excessive water and land use and high level of wastage. Compared with other commodities, meat wastage volumes are low, however the meat sector generates substantial carbon emissions and land pressure, especially in high-income countries in industrialized Asia, North America, Oceania and Latin America, and therefore should not be overlooked. China and the U.S. appear to provide the largest opportunities for GHG mitigation from consumption practices.[12] In addition, policy makers, civil society and private sector actors in China and the U.S. have shown willingness to address this issue and implement interventions. Reducing food losses may also have high gains, especially with regard to food security in Sub-Saharan Africa.

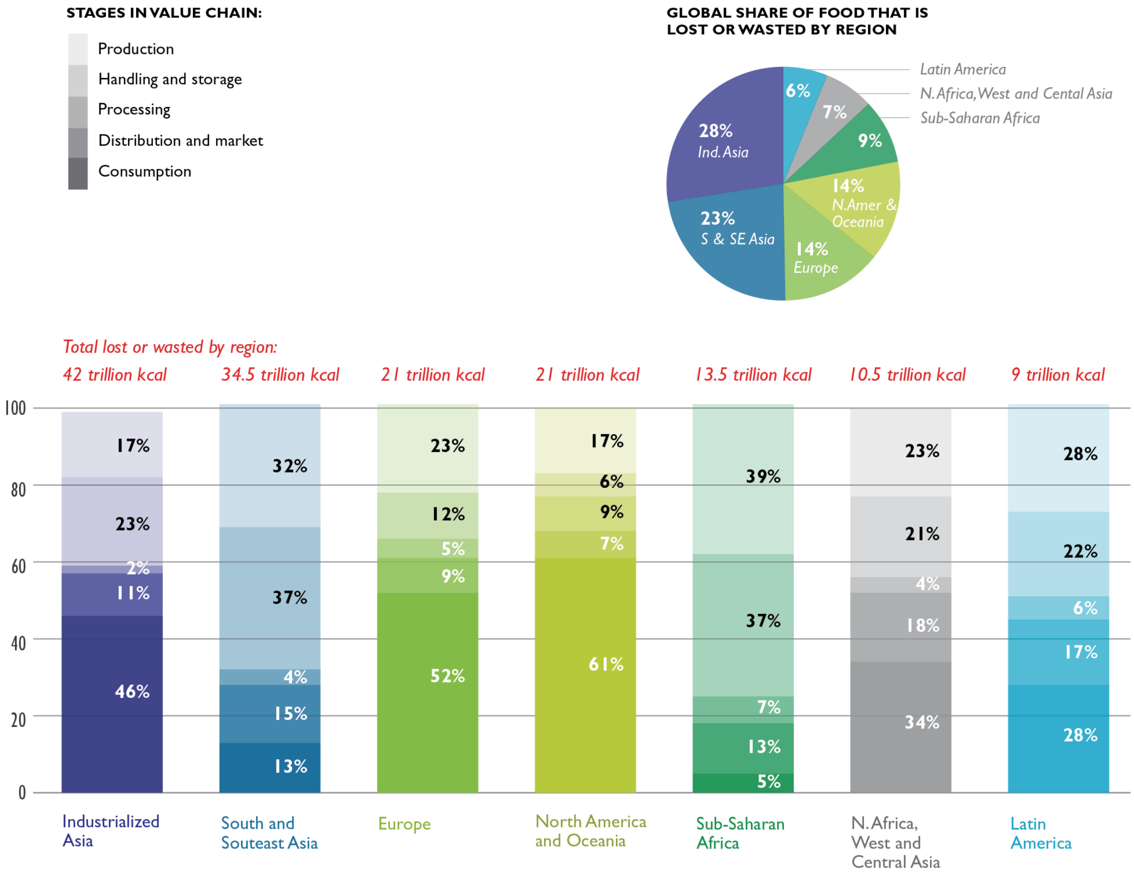
China. In China, USD 32billion worth of food is thrown away by end-consumers every year, enough to feed 200 million people,[13] while 128 million Chinese still live below the poverty line. The rate of food wastage in the entire supply chain is 19 percent ± 5.8 percent in China, with the consumer end having the largest portion at 7.3 percent ± 4.8 percent.[14] Large portion sizes and catering (restaurants) makes up a majority of food waste. In university canteens, one third of food purchased is wasted, and in urban residences, food waste has increased four-fold since the 1980s.[15] President Xi Jinping has been vocal about reducing waste since 2013, calling for consumer and government measures to address the issue. Government policies have been enacted that place restrictions on the use of government funds for wasteful banquets. The call to reduce waste has been echoed throughout China's mainstream media, and hundreds of anti-waste campaigns have since been launched online. The Chinese government has also launched public campaigns to reduce food waste and promote food scrap recycling.

U.S. In the U.S., 40 percent of all food produced is thrown away, even though 50 million Americans are food insecure.[16] Overconsumption and waste is usually due to shoppers not planning ahead, consumers and caterers serving large portion sizes, and consumers misunderstanding labels. The proliferation of diverse and inconsistent labels (i.e., 'sell-by', 'best before', and 'use-by') often confuse consumers in the U.S. and Europe, leading them to prematurely discard food they believe has become unsafe for consumption. A survey by the Food Marketing Institute found that 9 in 10 consumers in the U.S. accidentally throw food away due to misunderstanding of labels.[17] The U.S. government launched a national campaign called the U.S. Food Waste Challenge in June of 2013, with the aim to improve practices of farmers, manufacturers, retailers and consumers in reducing food wastage in the country.[18]

Sub-Saharan Africa. In Sub-Saharan Africa, 76% of food losses are incurred in production and handling and storage (see Figure 14). Methods including intensification and diversification of production, and the use of more effective handling and storage units could significantly reduce upstream food wastage. For postharvest handling and storage, some of the most cost-effective and practical techniques include the use of solar dryers, evaporative coolers, plastic storage bags, metal silos and plastic transportation crates, all of which have shown significant reductions in spoilage, pest infiltration and losses.[19] These methods can be particularly helpful for reducing wastage of cereals, fruits/vegetables, and roots/tubers, as well as having a positive effect on food security and livelihoods. The main barriers for farmers adopting these postproduction handling and storage techniques are awareness, education on their use, up-front costs, and availability. To address these challenges, extension services and aid programs could provide support to farmers to facilitate adoption.

Figure 14. Food waste by region and stage in value chain [20]

Percent of kcal lost or wasted. Totals are in trillion kcal. Colors match regions in bar chart below.



Source: FAO, 2013.

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[1] Food and Agriculture Organization of the United Nations. (2013). *Food wastage footprint: Impacts on natural resources.* Rome, Italy; Food and Agriculture Organization of the United Nations.

[2] Ibid.

[3] Ibid.

[4] Ibid.

[5] Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T. (2013). *Reducing Food Loss and Waste.* Washington D.C.: World Resources Institute.

[6] Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A. (2013*). Creating a Sustainable Food Future: Interim Findings.* Washington, D.C.: World Resources Institute.

[7] There have been many reports about the extent of food waste, but the actual quantities are still quite uncertain and the data is sparse. Quality of data therefore still needs substantial improvement.

[8] This estimate was extrapolated from Smith, P., Haberl, H., Popp, A., Erb, K., Lauk, C., Harper, R., Tubiello, F., de Siqueira Pinto, A., Jafari, M., Sohi, S., Masera, O., Bottcher, H., Berndes, G., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E., Mbow, C., Ravindranath, N., Rice, C., Abad, C., Romanovskaya, A., Sperling, F., Herrero, M., House, J., Rose, S. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*, 2285-2302. The 2030 mitigation potential was assumed to be half of the 2050 mitigation potential provided.

[9] The production of food that is lost or wasted uses an estimated 250 km3 of water and occupies approximately 1.4 billion hectares of land (~30 percent of the world's agricultural land. Food and Agriculture Organization of the United Nations. (2013). *Food wastage footprint: Impacts on natural resources.* Rome, Italy: Food and Agriculture Organization of the United Nations.

[10] Food and Agriculture Organization of the United Nations. (2013). See fn #1

[11] Ibid.

[12] Ibid.

[13] Zhou, W. (2013). Food Waste and Recycling in China: A Growing Trend? *World Watch Institute.* Blog Post. Retrieved 2013-2014, from http://www.worldwatch.org/food-waste-and-recycling-china-growing-trend-1.

[14] Liu, J., Lundqvist, J., Weinberg, J., Gustafsson, J. (2013). Food Losses and Waste in China and Their Implication for Water and Land. *Environmental Science and Technology, 47,*10137-10144.

[15] Ibid.

[16] Hall, K. D., Guo, J., Dore, M., Chow, C. (2009). *The progressive increase of food waste in America and its environmental impact.* PLOS ONE 4.

[17] Natural Resources Defense Council (NRDC) and Harvard Food Law and Policy Clinic. (2013). *The Dating Game How Confusing Food Date Labels Lead to Food Waste in America.* New York: Natural Resources Defense Council.

[18] USDA Office of the Chief Economist. (2013). U.S. Food Waste Challenge. Retrieved 2013-2014, from http://www.usda.gov/oce/foodwaste/.

[19] Food and Agriculture Organization of the United Nations. (2013). See fn #1; Lipinski, B. et al. (2013). See fn #5

[20] Food and Agriculture Organization of the United Nations. (2013). See fn #1

4.2
SHIFTING DIETARY TRENDS

Background

World meat production and consumption has grown exponentially since the 1960s, and is projected to grow an additional 70 to 80 percent by 2050 due to increasing income and population from emerging and developing countries (see Figure 15).[1] While there are countries and lower income segments of the population where protein intake levels are still lower than optimal, the majority of developed and emerging countries have increased consumption to unhealthy levels of meat protein.[2] This dramatic rise in meat consumption and production, especially of beef, causes considerable environmental damage including deforestation, water contamination and soil degradation. Additionally, overconsumption of meat (particularly red and processed meat) has been shown to increase the risk of human health problems including obesity, high blood pressure, diabetes, coronary heart disease and several forms of cancer.[3,4,5] High meat consumption has also largely led to industrialized agriculture practices that have been criticized for the use of antibiotics and hormones, and increasing risks in food safety and animal welfare.[6]

As detailed in Chapter 2, livestock production also has a large carbon footprint, accounting for approximately 50 to 70 percent of direct agricultural GHG emissions. When the full life cycle emissions of meat is considered, livestock account for 14.5 percent of total global GHG emissions, or a total of 7.1 Gt CO_2e per year.[7] While numerous researchers and institutions around the world are focused on reducing the carbon footprint of livestock production (supply), little has been done about the viability of curbing growth trajectories of meat consumption (demand).

Figures 15 and 16. World meat production by type (left) and the carbon intensity of food products (right)[8]

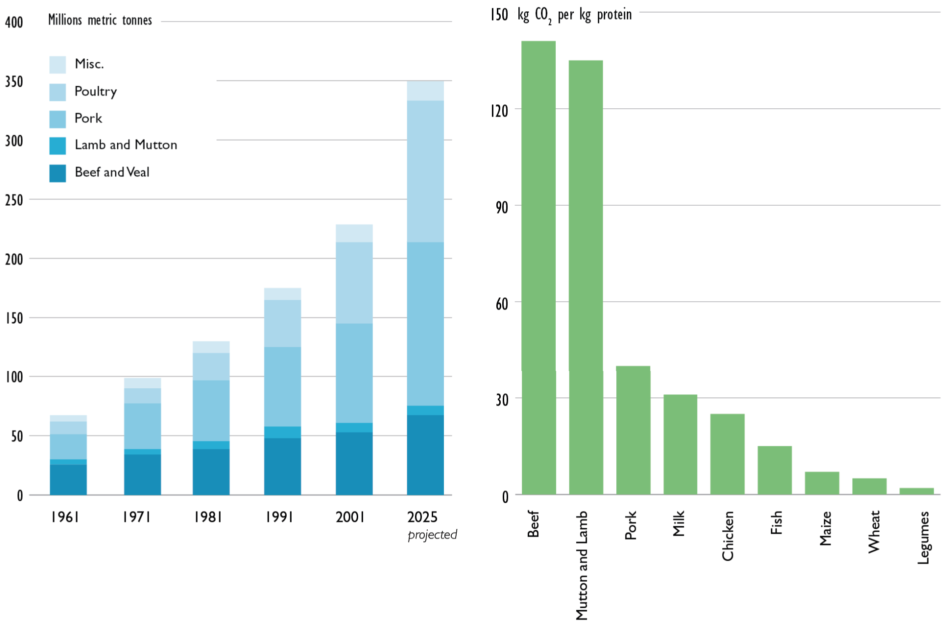
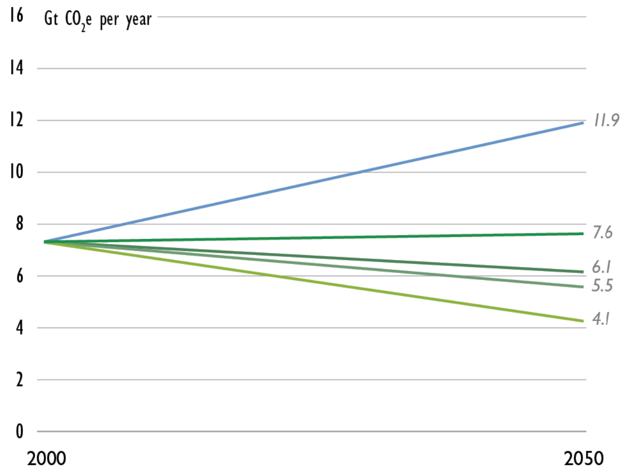


Figure 15 Source: Adopted from FAOSTAT and Elam, 2006.
Figure 16 Source: Gonzalez et al., 2011.

Reducing demand of meat by a relatively small amount would have a significant absolute impact on GHG emissions, human health and the environment associated with livestock production. The GHG emissions savings are especially sizable if consumption is shifted away from ruminants (e.g., beef), given that beef and milk production account for the majority of emissions (41 percent and 20 percent of the sector's emissions respectively), while pig meat and poultry meat/eggs contribute 9 percent and 8 percent respectively.[9] Beef has roughly six times the carbon footprint per kg of food than poultry, and poultry's carbon footprint is roughly ten times that of any of the major cereal crops. See Figure 16 for carbon intensity of food products.[10] Beef is also the least resource-efficient meat to produce per kilo than any other meat, requiring large amounts of water, energy, feed and land. Stehfest et al[11] calculated that a shift to a 'healthy diet'[12] would reduce emissions by 4.3 Gt CO_2e by 2050 compared with the baseline (see Figure 17), or roughly 2.15 Gt CO_2e by 2030. The mitigation potential increases to when ruminant meat (e.g., beef, mutton, lamb, buffalo) are replaced with lower carbon options.

Figure 17. Mitigation potential of shifting meat consumption[13]



AGRICULTURE AND LAND USE EMISSIONS SCENARIOS

11.9 baseline: all agriculture and land use emissions in a base case scenario (including soil carbon sequestration)

7.6 healthy diets: the global population adopts a diet based on recommendations from Harvard Medical School*

6.1 no ruminants: all ruminant meat is substituted by plant-based products

5.5 no meat: all meat is substituted by plant-based products

4.1 no animal products: all animal products, including eggs and milk, are substituted by plant products

** According to Harvard Medical School, a "healthy diet" prescribes daily protein intake as 90g per day. Additionally, the Institute of Medicine and Center for Disease Control and Prevention recommends a minimum of 0.8 grams of protein for every kilogram of body weight per day— or about 58 grams for a 160 pound adult. The FAO also recommends 58g. This compares with a typical daily American diet today of ~205g per meat per person. This diet leads to higher meat intake than in the reference case for some developing countries.*

Source: Stehfest et al., 2009 and Smith et al., 2013.

Co-benefits and trade-offs

Co-benefits	Trade-offs
Improved health and life expectancy Scientific evidence shows that reducing saturated fats and cholesterol, primarily from red and processed meat, reduces risks of cardiovascular diseases, cancer, stoke and diabetes.[14]	Shift to unsustainable fisheries While shifting diets towards less meat and non-ruminants, attention should be paid to avoid a consumption shift to unsustainable fisheries. Sustainable aquaculture may be a potential solution to protein provision in this instance.[15]
Increased food security Reducing the amount of land and grains used for livestock increases food availability by freeing available resources. A 2011 study revealed that reducing meat consumption could increase the global food supply by 50 percent by reduced pressure on croplands.[16]	Impact on prices Valuing the true cost of meat may cause prices to rise, making it unavailable to poorer segments of the population.
Reduced land conversion and environmental degradation Decreasing meat production, primarily of ruminants, reduces water use, soil degradation, pressure on forests, and manure and pollution into water systems.	

Regional focus

Global meat consumption is largely dominated by China (28 percent), the E.U. (15 percent), the U.S. (15 percent) and Brazil (6 percent). Projected growth rates of meat consumption in China, India and the rest of Asia are particularly high, increasing by 46 percent, 94 percent and 72 percent respectively by 2050. China's rising demand for meat is specifically notable given China's population of 1.3 billion; and the trend towards higher carbon intensive meats, with projected consumption of beef and mutton increasing 116 percent by 2050. It is also important to note that the U.S. still consumes the highest amount of meat per capita of any major economy, more than double what is considered appropriate for a healthy diet. For consumption of beef and mutton, Brazil, Argentina, the U.S. and Canada are far above the global average. See Table 3 for meat consumption trends and growth rates.

Table 3. Per capita consumption of meat products in 2006 and 2050[17]

Region	Livestock (kcal/person/day)			Beef and Mutton (kcal/person/day)		
	2006	2050	%change	2006	2050	%change
European Union	864	925	7%	80	75	-6%
Canada and USA	907	887	-2%	117	95	-19%
China	561	820	46%	41	89	116%
Brazil	606	803	33%	151	173	15%
Former Soviet Union	601	768	28%	118	156	32%
Other OECD	529	674	27%	64	84	31%
Latin America (ex. Brazil)	475	628	32%	59	86	45%
Middle East and North Africa	303	416	37%	59	86	45%
Asia (ex. China, India)	233	400	72%	24	43	79%
India	184	357	94%	8	19	138%
Sub-Saharan Africa	144	185	29%	41	51	26%
World	413	506	23%	50	65	30%

Source: Searchinger et al., 2012.

We suggest focusing on countries with the highest potential mitigation impact, these being primarily China and secondarily the U.S. These countries have also been identified as good candidates for interventions, given China's political structure and the population's proven ability to substitute diets, and the U.S. trend toward reduced beef consumption and healthier diets. The E.U. and Latin America, particularly South America, are also emissions hotspots with South America seeing a dramatic increase in beef demand per capita which merits attention.

China. In February of 2014, the Chinese government relinquished its historic self-sufficiency policy of being 95 percent self-sufficient in grains, indicating its intent to boost meat production by facilitating imports of cheaper grains, soy, corn and other feed.[18] China actively supports and protects domestic pork production, producing half of global output in 2010. Soy imports, which now account for about 75 percent of China's soy consumption, have roughly quadrupled since 2000.[19] In 2013, Shuanghui International acquired U.S. company Smithfield Foods, making it one of the largest meat (particularly pork) producer and processors in the world. Suffice to say that China is set on expanding its meat production, and has become a serious actor in the global industrial meat complex.

Interventions in China could be particularly effective, as the strategy would be to mitigate the projected growth of beef demand rather than changing existing consumer behavior—a relatively easier task. China's diets and strong cultural preference for other meats allows the avoided shift to beef without incurring losses in welfare or disrupting culture. Additionally, food and water security is one of the top priorities of the Chinese government. Pork is also considered a strategically important food source and the Chinese government actively supports and protects domestic pork production. Given beef production requires substantially more land, water and feed (grains) than other meats, it would not serve the interest of the government's food and water security goals to increase beef consumption and production.

U.S. In the United States, overall meat consumption is declining, albeit from a very high level. For the first time on record, U.S. per-capita meat consumption declined by 9 percent between 2007 and 2012.[20] Additionally, the U.S. has shifted its red meat consumption to poultry, seeing roughly a 27 percent decline in beef consumption per capita and a 50 percent increase in poultry since 1970.[21] However, red meat still represents the largest proportion of meat consumed (58 percent).[22] These trends can be partially attributed to the recession and increases in meat prices; however, many consumers cite health concerns as the primary reason for reducing meat consumption.[23] Research conducted by National Public Radio and FGI Solutions found that people are more likely to reduce their meat consumption when they are motivated by health concerns (62 percent cite health as the primary reason) in the U.S. Increasing consumer education of the health benefits of eating less meat can therefore influence a change in dietary habits. National campaigns including Meatless Mondays have been adopted widely since its inception, with schools, universities, government agencies and restaurants successfully raising awareness and encouraging people to reduce their meat consumption.[24]

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[1] Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A. (2013). *Creating a Sustainable Food Future: Interim Findings.* Washington, D.C.: World Resources Institute.

[2] A "healthy diet" recommended by Harvard Medical School is 90 g per day. The Institute of Medicine and Center for Disease Control and Prevention recommends a minimum of 0.8 grams of protein for every kilogram of body weight per day— or about 58 grams for a 160 pound adult. The FAO also recommends 58g.

[3] World Cancer Research Fund. (2007). *Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective.* Washington, D.C.: American Institute for Cancer Research.

[4] Larsson S., Wolk A. (2006). Meat consumption and risk of colorectal cancer: a meta-analysis of prospective studies. *International Journal of Cancer,199*, 2657–2664.

[5] Kant A., Graubard B. (2005). A comparison of three dietary pattern indexes for predicting biomarkers of diet and disease. *Journal of American College of Nutrition, 24,* 294–303.

[6] Chemnitz, C., Becheva, S. (2014). Meat Atlas: Facts and figures about the animals we eat. Heinrich Boll Foundation and Friends of the Earth Europe.

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

[8] Adopted from FAOSTAT and Elam, T. (2006) *Global Meat Consumption by type, 1961-2025.* (left); and Gonzalez, A., Frostell, B., Carlsson-Kanyama, A. (2011). Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation. *Food Policy, 36,* 562-570 (right).

[9] Gerber, P.J., et al. (2013). See fn #7

[10] Gonzalez, A., Frostell, B., Carlsson-Kanyama, A. (2011). Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation. *Food Policy, 36,* 562-570

[11] Stehfest, E., Bouwman, L., van Vuuren, D.P., den Elzen, M., Eickhout, B., Kabat, P. (2009). Climate benefits of changing diet. *Climatic Change*, 83-102.

[12] The study is based on Harvard Medical School's recommendation of daily protein intake as: 10 g beef, 10 g pork, 46.6 g chicken and eggs, 25.6 g fish, for a total of 90 g per day. However, the Institute of Medicine and Center for Disease Control and Prevention recommends a minimum of 0.8 grams of protein for every kilogram of body weight per day— or about 58 grams for a 160 pound adult. The FAO also recommends 58g.

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[13] Stehfest, E. et al. (2009). See fn #11
These scenarios were generated using an integrated assessment model (IMAGE 2.4) and Smith, P., Haberl, H., Popp, A., Erb, K., Lauk, C., Harper, R., Tubiello, F., de Siqueira Pinto, A., Jafari, M., Sohi, S., Masera, O., Bottcher, H., Berndes, G., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E., Mbow, C., Ravindranath, N., Rice, C., Abad, C., Romanovskaya, A., Sperling, F., Herrero, M., House, J., Rose, S. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*, 2285-2302.

[14] Johns Hopkins Center for a Livable Future. (2014). *Health & Environmental Implications of U.S. Meat Consumption & Production.* Retrieved 2013-14, from http://www.jhsph.edu/research/centers-and-institutes/johns-hopkins-center-for-a-livable-future/projects/meatless_monday/resources/meat_consumption.html#2m.

[15] Those species that can be grown in an environmentally benign way, in open water, without feed (e.g., mussels) clearly have the lowest GHG footprint of any animal protein, while those farmed on land and fed vegetarian feed (e.g., tilapia, carp) are also low carbon options.

[16] Foley, J., Ramankutty, N., Brauman, K., Cassidy, E., Gerber, J., Johnston, M., Mueller, N., O'Connell, C., Ray, D., West, P., Balzer, C., Bennett, E., Carpenter, S., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D. (2011). Solutions for a Cultivated Planet. *Nature, 478,* 337-342.

[17] Based on WRI analysis of Alexandratos, N. and J. Bruinsma. (2012). Source: Searchinger, T., et al. (2013) See fn #1

[18] Norse, D. (2012). *China's Food Security: Challenges and Responses in a Global Context*. Europe and China Research and Advice Network.; Ranallo, A., and Sharma, S. (2014) Change in grain policy signals China's intent to boost meat production. Institute for Agriculture and Trade Policy.

[19] Although we did not include land use emissions in this analysis, it is worth noting that roughly half of China's soy imports come from Brazil (the other roughly half come from the US). Soy has been associated with deforestation in the Brazilian Amazon.

[20] Searchinger et al. (2013). See fn #1

[21] U.S. Economic Research Service. (2011). Is and International Meat Consumption Chart. Retrieved 2013-14, from http://vegetarian.procon.org/view.resource.php?resourceID=004716.

[22] Daniel, C., Cross, A., Koebnick, C., Sinha, R. (2011).Trends in Meat Consumption in the United States. *National Institute of Health Public Health Nutrition, 14,* 575-583.

[23] FGI Research. (2012). 2012 Meatless Monday Online Panel. Retrieved 2013-14 from, http://www.meatlessmonday.com/images/photos/2012/10/FGI-Survey-Report.pdf.

[24] Ibid.

5.

CROSS-CUTTING STRATEGIES

No one single strategy can address the full mitigation potential of the agricultural sector. This suggests that a coordinated strategy should consist of a diversified portfolio. The reduction of GHG emissions at the source (supply) and through shifts in consumption (demand) are essential pillars of such a strategy. However, there are a number of cross-cutting measures that can facilitate the uptake of new practices and spur innovation. This chapter will review a number of such measures, with a particular focus on those that help to channel public or private funds into mitigation, or that allow for better accounting of the GHG footprint of the agricultural sector.

5.1
SUBSIDIES AND TRADE

Background

Access to finance, availability of financial support, and access to markets all play a key role in facilitating the transition to climate-smart agriculture. When countries decide to reduce emissions from agriculture, they have to establish policies and create incentives for emission reductions. Policy makers must also make knowledge and expertise available to farmers and ensure the necessary financial support that facilitates the transition to new practices. Government subsidies are the most common form of incentives in the agricultural sector. Currently only a small percentage of such subsidies are well-aligned with climate or other environmental goals.

Governments spend billions of dollars yearly on agricultural subsidies paid to farmers for production and agricultural inputs. When linked to production, these payments and pricing policies of agricultural inputs often lead to the overuse of pesticides, fertilizers, water and fuel, or encourage land degradation. Changing the incentive structure of such subsidies can increase the efficiency of the use of agro-chemicals and promote their replacement by agricultural practices (e.g., multi-cropping, crop-livestock integrated production, use of bio-fertilizers and bio-pesticides) which enrich the soil, reduce emissions and lower both agricultural production costs and import bills. Some countries are in the process of redirecting agricultural subsidies towards payments for environmental services, and these can include carbon storage or emissions reduction.[1] The move towards 'decoupled' payments unrelated to price and current output has provided an opportunity for a system of agricultural subsidies conducive to climate concerns. However, most agricultural subsidies still protect farmers from the risks associated with agricultural production, perhaps too much. Such subsidies reduce the incentives for the world to cope with country-specific risk through a fair, efficient, and undistorted trade regime. Additionally, subsidies complicate the agreement on mitigation incentives under the UN Framework Convention on Climate Change (UNFCCC).

International trade is increasingly important for global food security, in particular where productive capacities are impaired as a result of climate change. Countries will have to review their trade policies to ensure that they can compensate for decreases in domestic production through increased imports, and are able to exploit possible new comparative advantages through export. However, badly designed mitigation policies can also distort trade, with negative impacts on food accessibility and availability. The potential for conflict between climate change mitigation and trade rules have led some parties to the UNFCCC to argue that climate change negotiations would be an inappropriate forum for discussions of mitigation in agriculture and that attempts to create incentives for agricultural mitigation would lead to conflict with the trade regime. Trade negotiators on the other hand often refer to the UNFCCC as the forum where mitigation should be discussed. Lack of clarity around respective roles and jurisdictions aggravates the insecurities that characterize the relationship between agricultural mitigation, trade, and government regulation and finance.

Considering the relevance of government support for international agricultural mitigation and the relationship between market access, demand for commodities, agricultural practices, and mitigation, we recommend the following mitigation strategies that address national and international mitigation incentives: 1) the reduction of GHG emissions through a review and revision of agricultural subsidies in the U.S. and the E.U.; and 2) the removal of barriers and the creation of incentives for GHG mitigation under the World Trade Organization (WTO) and the UNFCCC.

GHG mitigation through subsidies reform

Incorporating climate change objectives into agricultural subsidies to reward mitigation is essential to avoid a further lock-in of unsustainable practices and to create incentives for activity shifts. However, any subsidy reform will need to be carefully planned and assessed, as subsidies generally run the risk of being challenged by foreign competitors and leading to potential conflicts over trade rules. Subsidies are not necessarily inconsistent with WTO rules, but their application is strictly circumscribed. In general, policies that restrict current activities (e.g., take land out of production via subsidies for sequestration) will have a depressing effect on production and are unlikely to encounter problems from a trade perspective.[2] On the other hand, implementing policies that subsidize particular practices that are intended to encourage outputs might be labeled as trade distortion. Subsidies that encourage climate mitigation will have to be backed by careful impact assessments and cost-benefit analyses to avoid perverse outcomes. U.S. and E.U. subsidies for biofuels provide a useful lesson in that respect (see Annex 2).

Given these complexities, the aim should be to identify and address the positive and negative aspects of farming on atmospheric GHG concentrations that are uncontroversial and relatively easy to measure.[3] Non-distorting ways to support farmers could include government services, food security programs, and a form of income support decoupled from production decisions (measures that fall into the category known as the 'green box' under the WTO).[4] Large-scale livestock enterprises are often already subject to environmental regulations adopted to control emissions. Co-generation of energy on farms can be rewarded and surplus energy can be transferred to the electricity grid. Reforestation for improved sequestration could easily be given more encouragement within current conservation programs. Conservation payments could also incorporate incentives for carbon sequestration.[5] Subsidies that support such measures are most likely to be consistent with trade rules if they form part of a comprehensive environmental program. In this context, it is important to support conservation-oriented NGOs in their efforts to advocate for sustainable subsidies and incentives to reduce GHG emissions rather than to increase them. While we focus in our recommendations on subsidy reform in the E.U. and U.S., subsidy reform should be supported in all countries, including developing economies, such as Brazil, India and China where subsidies are raising quickly (see Text Box 3).

While the E.U.'s Common Agricultural Policy (CAP) has made significantly more progress than the U.S. Farm Bill on identifying and implementing adaptation measures for farmers and incentives for climate-smart farming methods, both subsidy systems are still heavily focused on agricultural output for support. The CAP's incorporation of both binding requirements and positive incentives for environmentally friendly farming practices can be expanded, and an emphasis on subsidy payments for agricultural output alone can be curbed. The U.S. Farm Bill has very few positive incentive programs for reducing emissions and most have strict eligibility requirements. It also fails to provide adequate financing for the entire installation or implementation of a conservative program. The Farm Bill does have conservation compliance regulations that provide disincentives to farmers, but those disincentives are highly specialized (e.g., farmers who produce annually tilled commodity crops on highly erodible cropland without adequate erosion protection). A balanced approach between binding requirements and positive incentives for mitigation efforts should be maintained and fitted into the future E.U. CAP as well as the U.S. Farm Bill. To support such efforts, we recommend supporting the following activities:

Text Box 3: Rising Agricultural Subsidies in Developing Countries[6]

Subsidies for agricultural inputs and outputs often encourage overproduction and distort trade. This is mostly the case in the United States and Europe, but high subsidies are also found in Japan, India, China and other countries. Many developing countries have initiated their own large subsidy programs for water, energy, and fertilizers, even as these become increasingly fiscally unsustainable because of higher prices and greater need. At the launch of the Doha Development Round of Trade Negotiations in 2001, many developing and emerging economies—including Brazil, China and India—argued that the high agricultural subsidies in developed countries were artificially driving down global crop prices, unfairly undermining small farmers and maintaining poverty in many developing countries. Today, China's agricultural subsidies, estimated at USD160billion in 2012, now dwarf those in the U.S. (USD19billion) and E.U. (USD 67billion) combined. Brazil's agricultural subsidies have doubled in just three years, and now total about USD10billion, according to a recent government report.[i] And in India, price supports for wheat and rice grew by 72 percent and 75 percent respectively between 2005–06 and 2010–11, significantly exceeding those in the U.S.[ii]

It is therefore not surprising that one of the most controversial issues at the recent WTO ministerial meeting in Bali was not over developed country subsidies, but subsidies in developing countries.[iii] The principal concern was food security, with India arguing that it should be allowed greater flexibility to pay its farmers above-market prices for the crops that it buys for the government's domestic food stockpiles. Other developing countries such as Thailand, Pakistan, and Uruguay—all of which, like India, are major exporters of rice—contended that overpaid farmers in India could undercut producers in their own countries.[iv] To be clear, if targeted well, short-term subsidies can help developing countries to spur investment and innovation in their agricultural sector, close the yield gap and reduce rural poverty. However, badly planned subsidies can have opposite effects and remove incentives for innovation and investments.

Enhance international incentives for climate change action

Unresolved and unclear trade issues have played a major role in preventing agreement on agriculture under the UNFCCC. In fact, given the importance of agriculture trade for livelihoods, employment generation and economic development, negotiators have raised concerns about the potential socio-economic consequences of mitigation measures taken by their trading partners. Climate change mitigation measures that have emerged in recent years also potentially pose a number of challenges to the multilateral trading system. In this respect, international consensus on climate mitigation measures that are likely to be effective and, at the same time able to withstand a challenge under the WTO, is crucial. Based on such an understanding, governments can ensure that the rules and frameworks offered by the WTO and the UNFCCC respectively are conducive to support climate change mitigation and broader sustainable development goals.

In the absence of such an agreement, there is a risk that there will be a continued increase in climate-related disputes under the WTO. Countries can and do apply unilateral or plurilateral measures, which can challenge existing trade rules and lead to trade disputes. Since current WTO-rules were agreed upon before climate change was on the agenda of policy makers, dispute settlement panels do not have any trade-specific guidelines related to climate change to refer to in their considerations. Unless countries decide to leave these matters to the WTO dispute settlement, resolving these controversies will require international cooperation.[7]

To promote effective international and national incentives for agricultural mitigation, the reciprocal paralysis between international trade and climate regimes has to be overcome. Clear signals from one negotiation process may positively influence agreement under the other. A clear division of responsibilities between the two relevant bodies, the WTO and the UNFCCC, is vital to avoid a situation where both organizations defer to the other rather than taking action or become overloaded. It is important that each adheres to its specific competence:

- The UNFCCC is best placed to assess the effectiveness of climate mitigation policies. It also has a mandate to review and assess the impacts of such policies. A dedicated work program on agriculture under the UNFCCC, which could include components such as transparency measures, information sharing and dialogue and analysis, would strengthen the capacities of the organization, particularly in the area of agriculture and food security.

- The WTO, informed by climate change expertise at the UNFCCC, could address a set of critical issues at the interface between trade and climate change. Such issues include distinctions between products that have been produced using climate-friendly methods of production, border tax adjustments, free allowances of emissions, carbon standards and labeling, subsidies and intellectual property rights and transfer of technology. Members could agree on preferred domestic policy measures for climate change mitigation and adaptation in terms of effectiveness and minimally distorting effects on international trade in the same way that measures for domestic subsidies have been classified by color codes (amber, blue and green) by the trade body.[8] In this context, it would be useful to clarify the use of environmental standards under the WTO.

  A clarification of which mitigation measures are acceptable under the WTO may lead the way to domestic action and international agreements that support agricultural mitigation. Experience from discussions on forest certification and resulting labeling shows that discussions under the WTO may facilitate agreement among members on environmental standards and measures. Clarifications of the permissibility of measures may also facilitate the inclusion of climate change in bilateral or multilateral agreements, such as the E.U.-U.S. or the Pacific Free Trade Agreements. Examples for bilateral agreements that are WTO-compatible include the Voluntary Partnership Agreements within the E.U.'s Forest Law Enforcement, Governance and Trade (FLEGT) mechanism.

  Activity that reviews climate change mitigation with a WTO lens is timely considering the (small) package of Doha Round deliverables WTO ministers adopted in Bali in December 2013. This package—the first multilateral deal in nearly two decades—includes a deal on trade facilitation along with selected agriculture and development-focused provisions. Notably, the Bali ministerial declaration also included a pledge to develop a "work programme" during 2014 in order to deal with the various outstanding areas of the Doha talks, which provides an opportunity for philanthropic action.

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[5] Blandford, D et al. (2009). See fn #2

[6] Sources for Text Box 3: (i) http://e15initiative.org/brasilia-farm-subsidy-growth-not-distorting-trade/; (ii) Clay, J., (2013). Are agricultural subsidies causing more harm than good?, *The Guardian*, 8. August 2013; (iii) Bali Declaration, WTO document WT/MIN(13)/DEC/W/1; (iv) Why the WTO agreement in Bali has finally helped developing countries. Retrieved 2013-14, from http://www.theguardian.com/global-development/poverty-matters/2013/dec/06/wto-agreement-bali-helped-developing-countries-india

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[8] Blandford, D. (2013). *Strengthening the multilateral trading system: Measures To Address Climate Change Mitigation And Adaptation In Agriculture.* Geneva: The e15 Initiative.

5.2
FINANCE AND INVESTMENTS

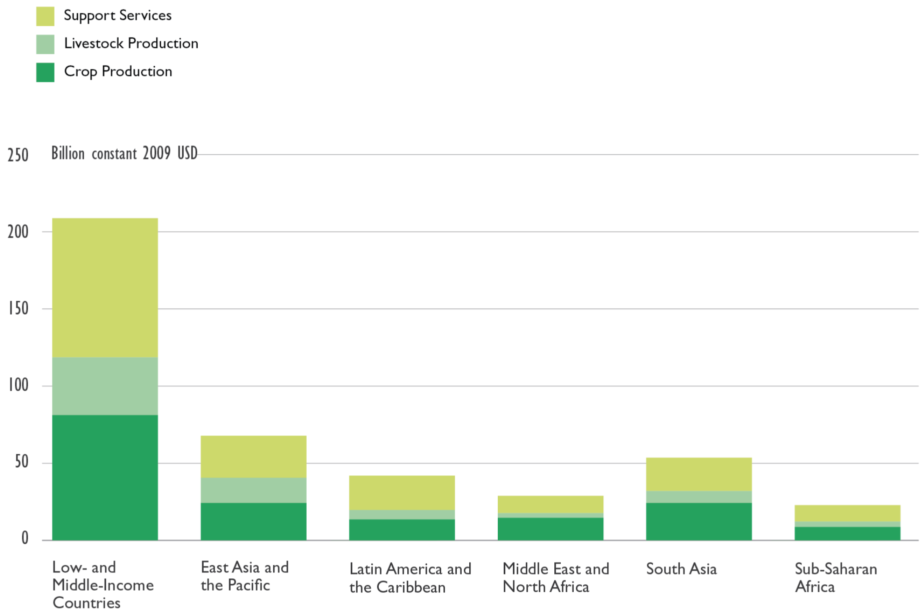
Background

After decades of decline or stagnation, international investment in the agricultural sector has increased.[1] During the last three decades, agricultural commodity prices sank to all-time lows (in real terms), along with yield growth in both high-income and low-income countries.[2] However, new social and economic pressures on the sector are redrawing this picture. Surging demand and constricted supply are attracting much larger flows of domestic and foreign capital into agricultural industries, particularly in developing countries. The public sector is also ramping up funding through official development assistance (ODA) and research and development (R&D) spending. The immediate drivers for today's trends include:

- Rapidly rising incomes, increasing food expenditures (especially meat, fish and milk products), and increasing imports from major emerging economies such as Brazil, China, and India.
- Biofuel initiatives relying on sugarcane, grains and oilseeds.
- Food price shocks (partly attributable to the above trends), and commodity shortages.
- 'New investors', such as sovereign wealth funds and speculative investors.[3]

Large private and public agricultural investments are required to meet projected agricultural demand. However, assessing exactly how much and what type of additional investment is needed, and by whom these investments should be made, is much more difficult. In 2009, FAO estimated investment needs of USD 9.2trillion by mid-century (USD 210billion annually from 2005–2050).[4] These projections embody a broad range of capital items related to primary livestock and crop production, as well as a number of activities in downstream support services, but do not account for climate change impacts or other constraints.[5] About 60 percent (USD 5.5trillion) of the total will be required to replace existing capital stocks. The remainder (about 40 percent or USD 3.6trillion) will be used to meet the additional agricultural product demand. Figure 18 shows the regional investment needed through 2050. Compared to these numbers, climate finance flowing into agriculture is expected to be marginal.[6] It is therefore essential that baseline financial flows into agriculture be re-directed towards low emitting, carbon rich and sustainable agricultural models.

Figure 18. Average annual investment needs for agriculture projected from 2005–2007 to 2050[7]



Source: Schmidhuber et al., 2009.

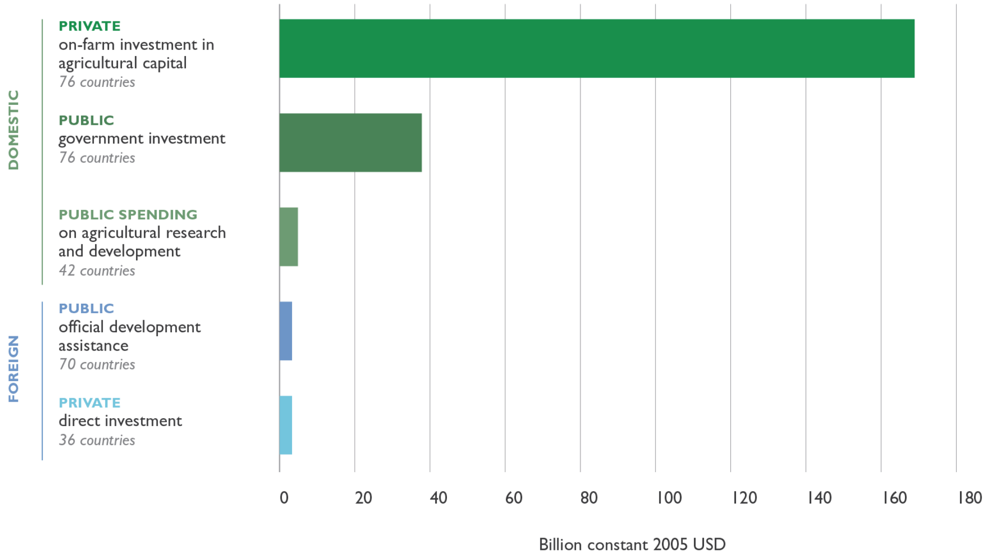
International finance for agricultural programs

The lion's share of agricultural capital needs will be covered by private domestic sources.[8] National level investments by farmers are by far the largest source of investment in agriculture (see Figure 19). On-farm investment in agricultural capital stock is more than three times as large as other sources of investment combined.[9] Investments by farmers can be influenced by government programs that create favorable conditions for investments, or through direct financial incentives (see Section 3.3.1. on *Subsidies and Trade*). Change can also come from different demands and requirements from traders, processors and retailers (see Section 5.3 on *Supply Chains*). Multilateral finance and ODA, which provide a comparatively smaller share of the overall funding can, nevertheless, play an important catalytic role in steering funds towards less emission-intensive practices.

In line with trends in agricultural investments, the share of agriculture in ODA declined from 19 percent in 1980 to 3 percent in 2006, yet is now increasing and estimated to be 6.4 percent in 2012.[10] FAO estimates that about USD 60billion of the USD 210billion to be needed annually in developing countries would have to be provided by public sources, from both foreign (ODA) and national governments. Investments are also needed for a transition to a more sustainable production that conserves natural resources and strengthens food security. To ensure that public investments in agriculture include climate mitigation considerations, we recommend the following interventions.

Figure 19. Investment in agriculture in selected low- and middle-income countries[11]

Explanatory Note: Data are averages for 2005–07 or for the most recent year available. Gross annual on-farm investment in agricultural capital stock (FAO, 2012a) is calculated using a 5 percent annual depreciation rate for the annual change in existing capital stock. Government investment is estimated using an assumption that 50 percent of government expenditures constitute investment. This assumption is based on a survey of agricultural public expenditure reviews, which give a mean of 42 percent for observations from a set of 12 countries. Official development assistance (ODA) is estimated using data from OECD (2012a); public spending on agricultural R&D is from IFPRI (2012a); and foreign direct investment (FDI) data are from UNCTAD (2011). No assumption is made regarding the share of R&D, ODA, and FDI that constitute investment.



Source: Adopted from Lowder et al., 2012.

Influencing the agriculture financing policies of donors (i.e., multilateral and national development banks, bilateral aid and philanthropy) to promote low emission development could prove to be an effective and highly catalytic strategy. While ODA and philanthropy makes only a small percentage of the overall investments into the agricultural sector (see Figure 19 above), both can influence government policies and create incentives for mitigation.

Similar considerations apply for climate finance. While the overall amounts of climate finance that will be available to support the transition to low emissions economies in developing countries remains uncertain, it is likely that the new financial mechanism under the UNFCCC's Green Climate Fund, will manage a significant portion of those funds.. Despite representing between 10 to 25 percent of global emissions, agriculture received only 2.5 percent of fast-start climate finance.[12] The decline of carbon markets further depressed the availability of climate finance for the agricultural sector. To ensure that agriculture receives due consideration in the allocation of international climate finance, it is critical to advocate for the support of international agricultural programs (e.g., on increased fertilizer efficiency, pasture restoration, mitigation in rice) through Green Climate Fund financing. Where carbon markets are unavailable or are poorly equipped to support larger scale agricultural mitigation programs, public funding channeled through international programs supported by the Green Climate Fund could become a force in unlocking significant agricultural mitigation potential.

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[4] Schmidhuber, J., J.Bruinsma, G. Boedeker. (2009). *Capital requirements for agriculture in developing countries to 2050.* Rome, Italy: United Nations Food and Agriculture Organization Economic and Social Development Department.

[5] USD 210 billion gross if accounting for replacement costs of depreciating capital goods; all estimates in constant 2009 U.S. dollars.

[6] As an example: The Global Environment Facility (GEF) to the UNFCCC show that over the 4th replenishment period of the Fund, out of a total of 228 approved projects, 33 related (partly) to agricultural activities (with USD 825million of GEF funding for all projects) and approximately USD 81million out of this for agriculture-related projects, excluding co-financing. The method of selecting whether projects solely or partly focus on agriculture is based on project outlines set out in GEF reports.

[7] The figure presents average annual needs over the period 2005-2007 to 2050. Source: Food and Agriculture Organization of the United Nations. (2012). *The State of Food and Agriculture*. Rome: Food and Agriculture Organization of the United Nations; data from: Schmidhuber et al., (2009). See fn#4

[8] Ibid.

[9] Food and Agriculture Organization of the United Nations. (2012). *The State of Food and Agriculture 2012*. Rome, Italy: Food and Agriculture Organization of the United Nations.

[10] Food and Agriculture Organization of the United Nations. (2012). See fn #9;

[11] Lowder, S., Carisma, B., Skoet, J. (2012). Who invests in agriculture and how much? An empirical review of the relative size of various investments in agriculture in low- and middle- income countries. Rome, Italy: Food and Agriculture Organization of the United Nations.

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5.3
CORPORATE SUPPLY CHAINS

Background

Each step along the agricultural supply chain involves GHG emissions (see Figure 20); from input producers all the way to consumers, via farmers, processers, traders, manufacturers and retailers. In addition to direct production emissions covered elsewhere in this report, major sources of emissions include energy use in cold chains and irrigation, fertilizer production, and black carbon as a result of agricultural fires, all which contribute to radiative forcing as well as direct GHG emissions.

Figure 20: Agricultural supply chains and example interventions points

As a result of increasing international trade in agricultural products for human consumption, international competition is has a growing influence over domestic supply chains. Specifically:

- Many processing companies source internationally as well as locally, leading to an increasingly complex of product formulation.
- Domestic companies compete with international exporters and/or import buyers for commodities. Accordingly, international market prices have a strong influence on domestic products.
- Suppliers of imported products compete with local farmers and processors for sales to domestic customers in several processed sectors.

Across supply chains it is becoming increasingly difficult to assure the availability and quality of raw materials. Security of supply is becoming a key concern for business, especially in the food and agricultural sectors. Companies sourcing from areas affected by climate change are particularly vulnerable. To mitigate climatic, environmental, and social risks, companies increasingly look for strategies to better ensure a sustainable supply of raw materials.[1] At the same time, consumers, especially those in developed countries, but increasingly those in emerging economies as well, have become more concerned about the environmental and social impacts of agricultural production. As a result, down-stream, consumer-facing companies have been under increasing pressure to improve the sustainability of their products across the full supply chain, particularly with respect to deforestation.

Sustainability can be improved at any stage, from fertilizer production to consumer waste handling, and through various leverage points, depending on the scope and integration of the supply chain. Examples of supply chain initiatives range from multi-stakeholder dialogues, information disclosures, and corporate social responsibility reports and strategies, to technical assistance, guidelines for better practices, standards, certification schemes and industry commitments (see Text Box 4 for examples). Typically, softer measures such as guidelines for better practices have evolved to standards and certification schemes that are monitored, evaluated, verified, and in some cases incentivized by public policies, or even enforced by regulations.

Text Box 4. Examples of supply chain initiatives[2]

Roundtables and commodity-specific initiatives. Partnering with large food industry, civil society—often with support of foundations—has played an important role in establishing multi-stakeholder dialogues to define and support sustainability for major agricultural commodities. Often large food conglomerates and agribusinesses are key partners in these efforts. The Roundtable for Sustainable Palm Oil initiated by the World Wide Fund for Nature (WWF) in 2004 is the most advanced effort internationally and has achieved wide participation with multiple stakeholders and a market share of 15 percent. It provides a platform for comprehensive sustainability principles and standards, including a module for GHG lifecycle analysis, a certification scheme and a trademark. A Global Roundtable for Sustainable Beef was launched in 2012, but no certification or GHG accounting scheme has yet been developed. Other commodity-specific initiatives led by private organizations and/or civil society include: the Roundtable on Responsible Soy, the Roundtable for Sustainable Biomaterials, Bonsucro, the Rainforest Alliance, and UTZ.

Protocols. The World Resources Institute (WRI) is currently developing a GHG Protocol Agricultural Guidance intended for corporate inventories along the supply chain or initiatives that are developing mitigation tools or metrics. The Agricultural Protocol will build on the Corporate Standard, widely used in other sectors. Additionally, WRI is also developing the Global Food Loss and Waste Measurement Protocol to serve as a tool for better management of waste in the supply chain.

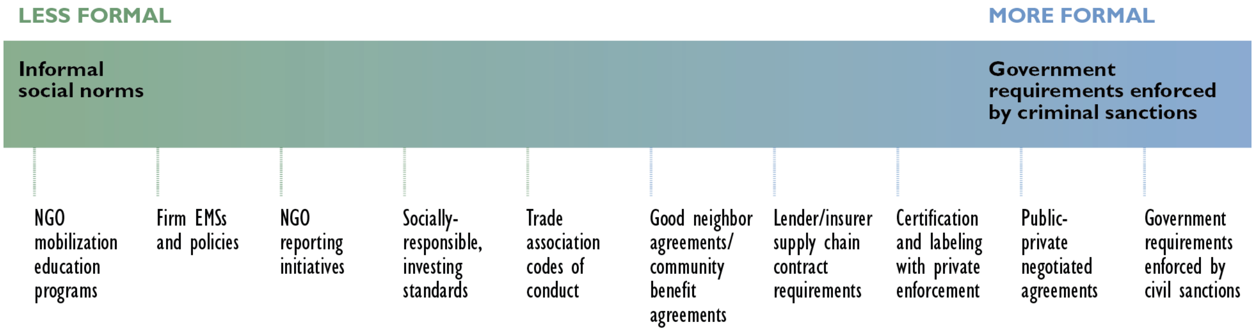
Voluntary principles. In December 2013, Sustainable Agriculture Initiative (SAI) published voluntary principles for sustainable beef farming, which were endorsed by major market actors, including McDonalds and Unilever. The SAI is a global food industry organization with the objective to facilitate initiatives and precompetitive information sharing to support the development and implementation of sustainable agriculture practices involving different stakeholders of the food chain.

Benchmarking tools. The Field to Market, Alliance for Sustainable Agriculture is an initiative of global corporations including producers, agribusinesses, food and retail companies, and conservation organizations. It was launched by the non-profit Keystone Center with the objective to improve sustainability of agricultural supply chains. The Alliance provides a Fieldprint Calculator, a web-based foot-printing tool that allows farmers to explore and benchmark GHG emissions and various other objectives for different farming practices.

Sourcing tools. The Linking Worlds initiative by the Sustainable Food Lab seeks to improve sustainability of sourcing from smallholder farmers. The Sustainable Food Lab is a partnership between Oxfam Unilever, Rainforest Alliance, among others. The initiative provides guidance and specific tools for sustainable sourcing from smallholders, including tools for value chain mapping, a business model canvas and principles.

Supply chain initiatives vary in their levels of scrutiny and enforcement, and are also often limited by the necessary compromises that characterize multi-stakeholder agreements as well as the voluntary nature of many of the initiatives. Figure 21 illustrates the range of formal interventions. The pragmatic approach of voluntary and corporate initiatives is both their enabling and limiting factor. It can allow initiatives to gain market share and the participation of multiple stakeholders much more quickly than public interventions. However, transformational change across the market requires strong incentives, such as consumer pressure and a business case. In some contexts, interaction with the public sector is essential to advance enabling environments and incentives for improvements that are unlikely to advance further under voluntary approaches. The E.U. policy for biofuels provides an example of public policies interacting with voluntary initiatives. The policy sets mandatory sustainability criteria, including requirements for minimum GHG emissions savings for member states counting feedstocks originating from third countries towards their renewable energy commitments. Accredited versions of voluntary standards may be used to prove compliance such as the rules adopted by the Roundtable on Sustainable Palm Oil and the Roundtable on Sustainable Biomaterials (see also Annex 2 on biofuels).[3]

Figure 21: Range of interventions from informal social norms to regulatory requirements[4]



Source: RESOLVE, 2012.

Climate change mitigation and certification systems

To date, there are more than 100 different voluntary sustainability standards and certification systems available.[5] Most have a focus on specific commodities, sectors and objectives. Standards focus on environmental and social (e.g., Fairtrade certification), and/or economic or business issues (e.g., UTZ Certified). Most standards incorporate environmental considerations to some degree, though some are primarily focused on health and safety issues (e.g., GlobalGAP). While more than 20 different GHG accounting tools are available for the agricultural sector,[6] very few standards directly consider mitigation aspects. Moreover, no standards have specifically considered yield or efficiency aspects,[7] despite their relevance for intensification and its potential for improved emissions efficiency along the agricultural supply chain (see Section 3.1 on *Sustainable Intensification*).

There is still a high degree of variability across existing certification systems with little or no understanding of the impact and potential of supply chain initiatives for climate change mitigation. Climate change is a relatively intangible threat and is unlikely to create sufficient consumer or government pressure for market transformation. To make a case for mitigation, agricultural supply chain initiatives need to: 1) deliver a business cases or incentives (e.g., profitability gains, quality concerns, supply traceability and security, reputational risks, regulatory risks, opportunities for brand development or new markets)[8]; 2) make co-benefits or trade-offs less elusive (e.g., deforestation); and 3) clearly define improvements and better practices and translate into metrics.

At the base of the supply chain (e.g., at producer or grower level), business and trade relationships are less concentrated than at the retail and processing level due to the diversity of small producers. Consumers and public policies originating from import countries exercise little influence over third or fourth-tier suppliers. Intermediaries such as commodity traders and primary processors have a potential influence, but their scope is limited by their relative anonymity and by the low level of public and regulatory pressure exerted on them. In particular, up-stream associations and cooperatives, and companies in the 'middle' of supply chains (traders and processing companies) play a key role in agricultural supply chains, as they typically have much more direct access to primary producers. However, understanding their motivations and interests is limited.

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[1] Steering Committee of the State-of-Knowledge Assessment of Standards and Certification. (2012). *Toward Sustainability. The roles and limitations of certification.* Washington, D.C.: RESOLVE, Inc.

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[2] Sources for Text Box 4: SAI Platform 2013; Schouten, G., Leroy, P. and P. Glasbergen (2012). On the deliberative capacity of private multi-stakeholder governance: The Roundtables on responsible soy and sustainable palm oil. *Sustainability in Global Product Chains, 83,* 42-50; GHG Protocol 2013. GHG Protocol Agriculture Guidance; De Man, R. and A. Ionescu-Somers. (2013). *Sustainable Sourcing of Agricultural Raw Materials - a Practitioner's Guide: Test Manual for Phase 1*. Sustainable Agriculture Initiative (SAI) Platform, IMD's Corporate Sustainability Leadership Learning Platform, the International Trade Centre (ITC),the Sustainable Trade Initiative (IDH), BSR, the Sedex Information Exchange (Sedex) and the Sustainable Food Laboratory (SFL)

[3] European Commission. (2013). Biofuels Sustainability Criteria. Retrieved 2013-14, from http://ec.europa.eu/energy/renewables/biofuels/sustainability_criteria_en.htm.

[4] Steering Committee of the State-of-Knowledge Assessment of Standards and Certification. (2012). See fn #1

[5] International Trade Centre. *Standards Map Compendium – 100 voluntary standards "At a Glance"*. Retrieved 2013-14, from http://www.standardsmap.org/uploadedFiles/standardsmaporg/Standards Map Compendium - 2013 - At a Glance- WEB.pdf .

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5.4
TRACKING EMISSIONS IN AGRICULTURE

Background

Measuring and monitoring GHG emissions is fundamental for managing emissions effectively. A robust understanding of how much carbon can be sequestered, or how much GHG emissions can be reduced by different practices, is central to making informed decisions about the most appropriate mitigation strategies. Measuring and monitoring emissions is also required to enable governments to implement policies and incentive frameworks. To establish a complete understanding of GHG emissions from the major agriculture-related activities, a comprehensive monitoring system needs to track both the emissions directly related to agricultural activities as well as the emissions that arise directly or indirectly along the agricultural supply chain. In addition, there is a need to better understand the carbon footprint of investments made in agriculture, so that measures can also be taken in this area.

Measuring the different GHG emissions from agricultural activities is a challenging task. Many of the available methods for emission quantification and monitoring are expensive and complex.[1] There are still large uncertainties associated with measurements of livestock, rice, and nitrogen fertilizer emissions.[2] In developing countries, measurements of agricultural emissions are even more difficult than in developed countries. In livestock, for example, emissions per head depend on animal type, body mass, diet and activity level, among other factors. These variables are quite different across farming systems, breeds, and diets, but currently the calculation factors used for the estimates are calibrated using breeds, management practices, and feeds common to temperate regions. Monitoring fertilizer emissions also remains challenging as nitrous oxide emissions depend on an array of variables that are very location and management specific. The measurement of soil carbon stocks and flows is also burdened with uncertainties related to emission factors attributed to possible mitigation practices, verification of implementation, and a lack of research on the impacts of agricultural management practices on non-CO_2 emissions.[3] Measuring of the carbon footprint of agricultural supply chains, in particular of processed food, is also complex.

A number of organizations and industry groups have made commitments to reducing emissions through supply chain-based approaches.[4] To date, however, the majority are still grappling with the challenge of developing an approach for tracking emissions reductions from agricultural production all the way to the end consumer. These challenges lead to relative uncertainty in our ability to understand the credibility and impact of these commitments, as well as to uncertainty regarding how to implement and allocate costs associated with these commitments across the supply chain.

Olander et al. (2013)[5] provides a good overview of the main challenges in this area, including:

- The need for user-friendly methods for GHG quantification that work across scales, regions and systems;
- The need for low-cost, easy to apply approaches;
- The need for methods that can span a range of different end uses, such as emission reduction strategies or reporting;
- The need for better clarification of uncertainty levels and rules for appropriate use;

- The need for common reporting metrics that are easy to use by policy makers and other end users; and
- The need for capacity development, particularly in developing countries, to monitor land use and land use change and associated emissions.

To date, there are very few on-going integrated monitoring efforts that can provide information across different sets of emission, environmental, agricultural and socio-economic variables, and that allow for understanding the outcomes of policy measures across these domains. The collection and analysis of emissions data is currently done primarily by national level entities and forms the basis for different types of modeling approaches used in projects and by research institutions to quantify GHG emissions. Direct measurements that supplement these models are difficult and costly.

These efforts are complemented by networks of governments, scientists or institutions, such as the Global Research Alliance on Agricultural Greenhouse Gases[6] and GRACEnet (Greenhouse Gas Reduction through Agricultural Carbon Enhancement network), which aim to improve the consistency of field measurement and data collection for soil carbon sequestration and soil nitrous oxide fluxes, and the Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems (SAMPLES)[7] project, which focuses on smallholder agricultural systems. There are also crop-specific measurement, reporting and verification (MRV) projects, such as the MIRSA (Mitigation in Irrigated Rice Systems: Guidelines from Measurement, Reporting and Verification) project, and regional efforts, such as The Technical Working Group on Agricultural Greenhouse Gases (T-AGG), which assembles the scientific and analytical foundation to support the implementation of mitigation activities on U.S. production agricultural and grazing lands. NGOs and private entities have developed the Cool Farm Tool,[8] a farm-level open source GHG calculator, the World Resources Institute GHG Protocol for Agriculture (under development), and other benchmarking tools. Finally different carbon standards (e.g., Verified Carbon Standard, the American Carbon Registry) have also developed GHG MRV protocols.

However, significant gaps continue to exist, particularly in developing countries where there are still many questions related to the sources of agricultural emissions, as well as an absence of methods and methodologies that allow the monitoring of emissions through supply chains and the evaluation of GHG impacts of investors. Considering the relevance of tracking emissions for any valuable mitigation action, and the particular characteristics of philanthropic support, we consider the area of GHG MRV improvement for governments, the private sector, and NGOs to be a priority action.

GHG emissions from agricultural sources

Most global monitoring systems for environmental, agricultural or socio-economic data are segregated by a small set of variables in these fields. In addition, a review of these monitoring systems has found that the majority of them lack the ability to provide the information in a way that can influence policy making and behavioral change. They also do not address the question of possible synergies or trade-offs across multiple management goals for agriculture.[9] In developing countries in particular, the availability and quality of integrated data on agricultural systems vary greatly. High-resolution, detailed geospatial databases that include current levels of nitrogen inputs, energy and water use and carbon stocks and flows are needed for determining mitigation potentials, and best mitigation options for the different agricultural typologies.

Simple models that can be used by non-experts would allow accounting (albeit with a certain inaccuracy) for GHG emissions from agricultural production. Such models could take simple inputs on the key variables and calculate emissions. They would be automatically parameterized and only need relatively simple inputs from users. The COMET-FARM system in the U.S. is an example.

GHG emissions in supply chains

The full accounting of upstream and downstream GHG emissions would allow for a more complete picture of climate impacts throughout the value chain. A range of initiatives exist that aim to quantify 'on farm' emissions reductions,[10] yet very few, if any, of these provide protocols and methodologies for tracking emissions reductions through production systems (also referred to as Scope 3 emissions[11]). A protocol that allows the tracking of GHG emissions from source to consumer would promote transparency throughout the agricultural supply chain. Such an initiative could build on existing efforts and standards to estimate emissions at the source and throughout the supply chain and serve as a starting point. More specifically, it could complement the WRI GHG Agricultural Protocol[12] by developing specific guidance and protocols for particular agricultural systems and geographies. Life cycle analysis undertaken by FAO for various products can further inform this effort.

GHG reporting for investors

Acting as market makers, capital providers and advisers, financial institutions and portfolio investors are important actors in the shift to a low-carbon economy. They have begun to report the emissions impact of their investments in the industrial, energy and infrastructure sectors. However, agricultural emissions remain largely unreported. To date, uncertainty with regard to the economic mitigation potential is one of the main barriers for steering investments towards more sustainable practices. Neither investors nor public agencies would be able to evaluate the climate impact of particular activities, considering the state of scientific knowledge, vast scope of activities, diversity of agricultural landscapes, and inherent uncertainties associated with climate change impacts. It is, therefore, a priority to develop frameworks for reporting agricultural emissions, including emissions from investments. Such frameworks would have to enable financing organizations to assess the climate impact of agricultural investments and monitor the actual emissions during the investment cycle.

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[4] For example the Consumer Goods Forum's zero deforestation commitment, the Sustainable Trade Initiative (IDH), and Unilever's Sustainable Agriculture code.

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[9] Olander, L. et al. (2013). See fn #1

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