STRATEGIES FOR

Mitigating Climate Change in Agriculture

Recommendations for Philanthropy

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Recommendations for Philanthropy

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AUTHORS:

Amy Dickie [1]
Charlotte Streck [2]
Stephanie Roe [2]
Monika Zurek [2]
Franziska Haupt [2]
Alex Dolginow [1]

CONTRIBUTING AUTHORS:

James Amonette [3]
Matthew Elliott [1]
Merrian Goggio Borgeson [1]
Erin Hafkenschiel [1]
Charlie Parker [2]
Lauren Stanley [2]
Paul West [4]

1. California Environmental Associates
2. Climate Focus
3. Pacific Northwest National Laboratory
4. Institute on the Environment, University of Minnesota

WEB PLATFORM:

www.agriculturalmitigation.org contains a copy of this report, the abridged report, the executive summary 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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TECHNICAL AND STRATEGIC ADVISORY PANEL

Barbara Bramble, *National Wildlife Federation*

Bruce Campbell, *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*

Tony Cavalieri, *Bill and Melinda Gates Foundation*

Achim Dobermann, *International Rice Research Institute (IRRI)*

Mario Herrero, *Commonwealth Scientific and Industrial Research Organization (CSIRO)*

Jon Hillier, *University of Aberdeen*

Leslie Lipper, *Food and Agriculture Organisation of the United Nations (FAO)*

Ricardo Meléndez-Ortiz, *International Center for Trade and Sustainable Development (ICTSD)*

David McLaughlin, *World Wide Fund for Nature (WWF)*

Michael Obersteiner, *International Institute for Applied Systems Analysis (IIASA)*

Marc Sadler, *The World Bank*

Philip Thornton, *International Livestock Research Institute and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*

Jan Kees Vis, *Unilever*

Paul West, *Institute on the Environment, University of Minnesota*

Lini Wollenberg, *University of Vermont and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*

PEER REVIEWERS AND CONSULTED EXPERTS ON RECOMMENDATIONS, AND ANALYSES

David Blandford, *Pennsylvania State University*

Robert Boddey, *Brazilian Agricultural Research Corporation (EMBRAPA)*

Leonardo Fleck, *Moore Foundation*

Manget Garg, *National Dairy Development Board, India*

Pierre Gerber, *Food and Agriculture Organisation of the United Nations (FAO)*

Dana Gunders, *Natural Resources Defense Council (NRDC)*

Karin Kaechele, *The World Bank*

Promode Kant, *Institute of Green Economy*

Ermias Kebreab, *University of California, Davis*

Odin Knudsen, *Real Options International*

Brian Lipinski, *World Resources Institute (WRI)*

Peggy Neu, *Meatless Mondays*

Marina Piatto, *Imaflora*

Debbie Reed, *Coalition on Agricultural Greenhouse Gases*

Peter Riggs, *Pivot Point*

Bjoern Ole Sander, *International Rice Research Institute (IRRI)*

Tim Searchinger, *World Resources Institute (WRI)*

Timm Tennigkeit, *UNIQUE Forestry and Land use*

Nathalie Walker, *National Wildlife Federation*

Reiner Wassmann, *International Rice Research Institute (IRRI)*

Andreas Wilkes, *Values for Development UK*

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 Recommended 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.

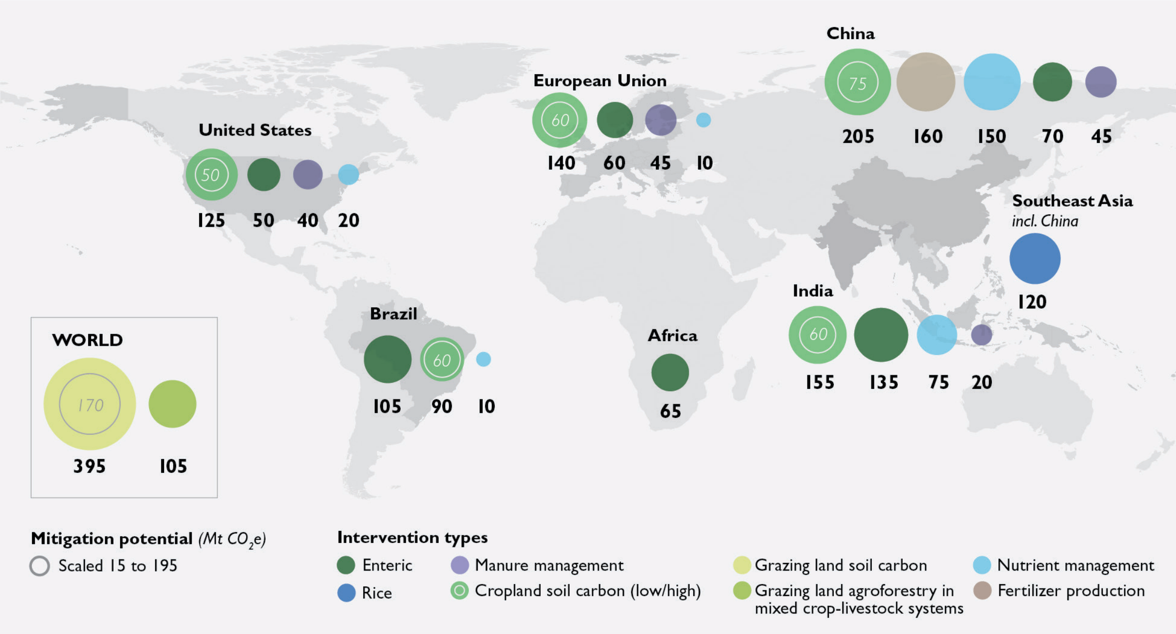
Building on the technical assessment of mitigation potential, this report identifies priority areas for mitigation based on the feasibility of engagement. For each priority country and commodity, a more in-depth analysis was conducted to determine whether and how the mitigation potential might be achieved. 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.

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 31.



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 for the philanthropic community. 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 CLUA's 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.

Our recommendations are shaped by the specific context in which the philanthropic sector operates. At its best, philanthropy has the advantage of being targeted, strategic, and nimble in its decision-making. Philanthropy also operates largely outside of inter- and intra- government decision-making processes, and generally does not have local, on-the-ground capacity. Further, philanthropy as a whole has relatively few financial resources compared with either public agencies or the private sector, and therefore must look for catalytic opportunities where relatively small investments can change the incentives or behaviors of large institutions and/or large numbers of small actors. The recommendations presented in this report are based on the following assumptions:

- Funds available for deployment to the agriculture-climate nexus are philanthropic in nature, are limited and generally do not exceed USD 20million for individual strategies and USD 5million for individual grantees.
- Strategies do not require a change in funding by government programs or the implementation of larger development programs, but there is opportunity to align and coordinate with such efforts.
- Funders have an interest in climate change mitigation and operate outside of the existing networks of agricultural funders.

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

This report presents both a comprehensive, quantitative, global mitigation assessment for the agricultural sector, and an evaluation of the political and social feasibility of interventions.

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. For each priority country and commodity, a more in-depth analysis was conducted to determine whether and how the mitigation potential might be achieved. We used the following steps to filter opportunities and develop the specific recommendations:

- Select top potential mitigation opportunities from Chapter 2.
- Assess co-benefits and trade-offs. Since one of our overarching objectives is to better integrate food security and agricultural economic development objectives with a climate change agenda, we prioritized opportunities where these objectives are aligned.
- Identify priority regions and countries for engagement. To evaluate the socio-political context within countries and assess agendas or policies that may provide opportunities for considering agricultural mitigation.
- Determine objectives. To realize the mitigation potential in the selected priority countries, specific objectives for philanthropic interventions have been established.
- Develop interventions. To describe concrete interventions and identify actions that can be supported by philanthropy as a path to achieving relevant mitigation action.

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.

Finally, the concluding section of this report, Chapter 6, highlights common themes and notes overlaps and synergies among the interventions. This section is provided to facilitate planning based on intervention issue, intervention type, and/or geographies.

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2.

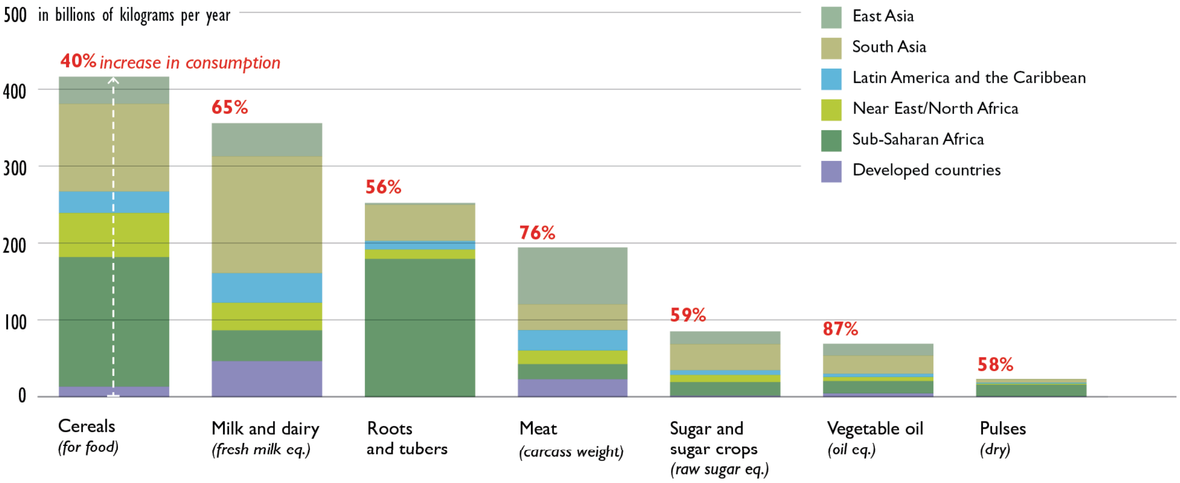
SOURCES OF AGRICULTURAL EMISSIONS AND MITIGATION POTENTIAL

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]

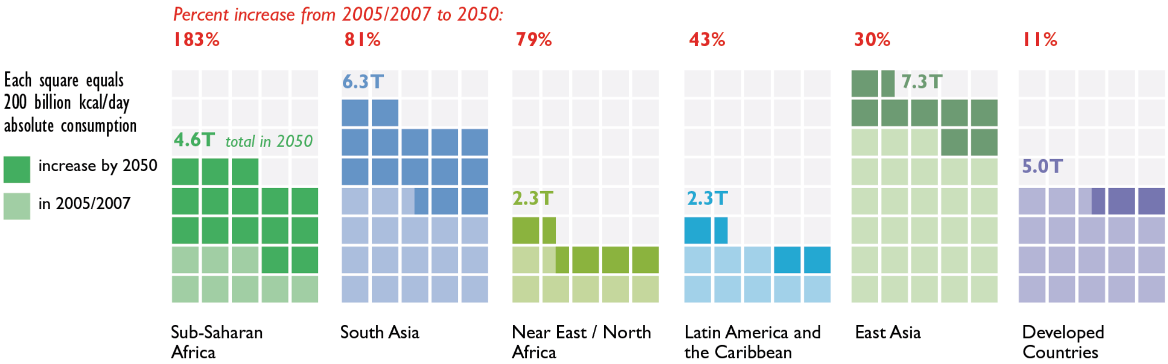
Figure 1: Growth in food consumption by 2050, relative to 2005-2007[5]



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.

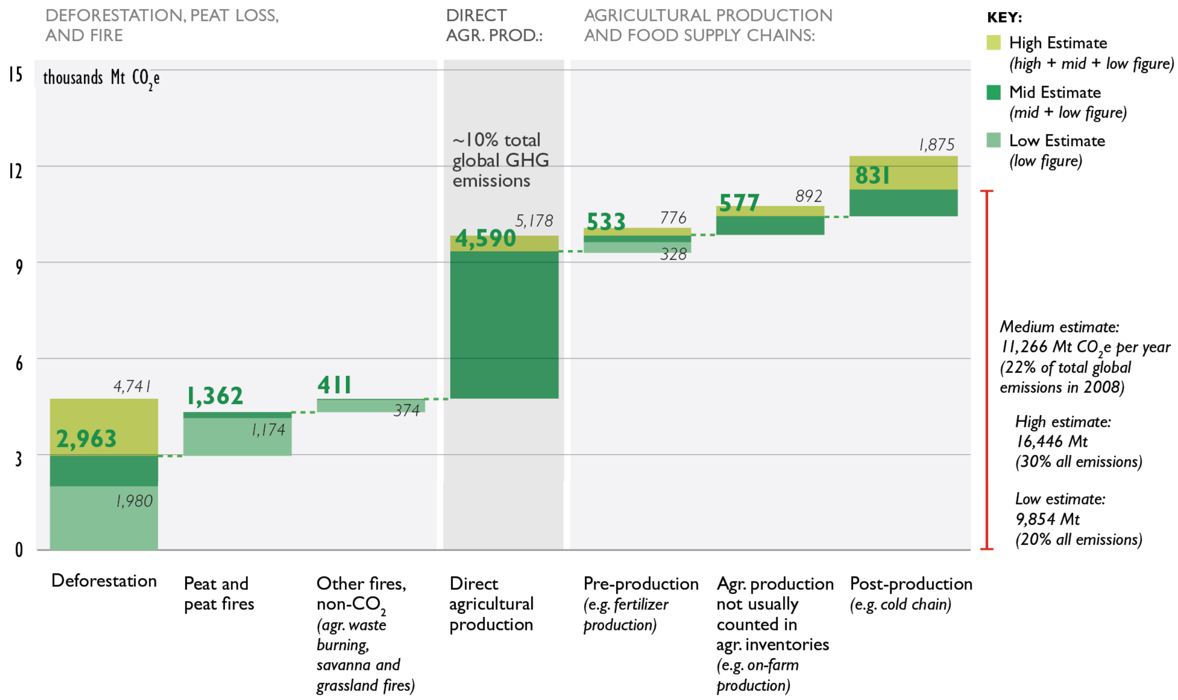
Emissions from the agricultural sector are very substantial, especially when accounting not only for emissions from direct production, but also for fossil fuel emissions along the agricultural supply chain, and emissions associated with agriculture's role in driving deforestation. Currently, roughly 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 greenhouse gas 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]

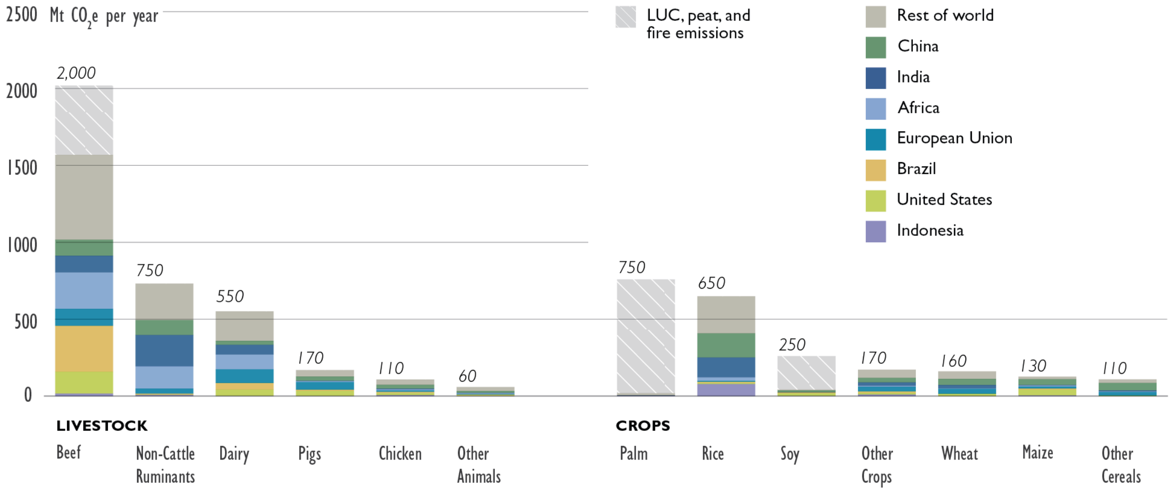
Sources of emissions	%
Enteric fermentation Ruminants (e.g., cattle, sheep, goats, water buffalo) emit CH_4 directly as a byproduct of digestion.	43%
Manure deposited on grazing lands Manure and urine that falls on grazing lands causes N_2O emissions.	16%
Synthetic fertilizers N_2O emissions from soils 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]



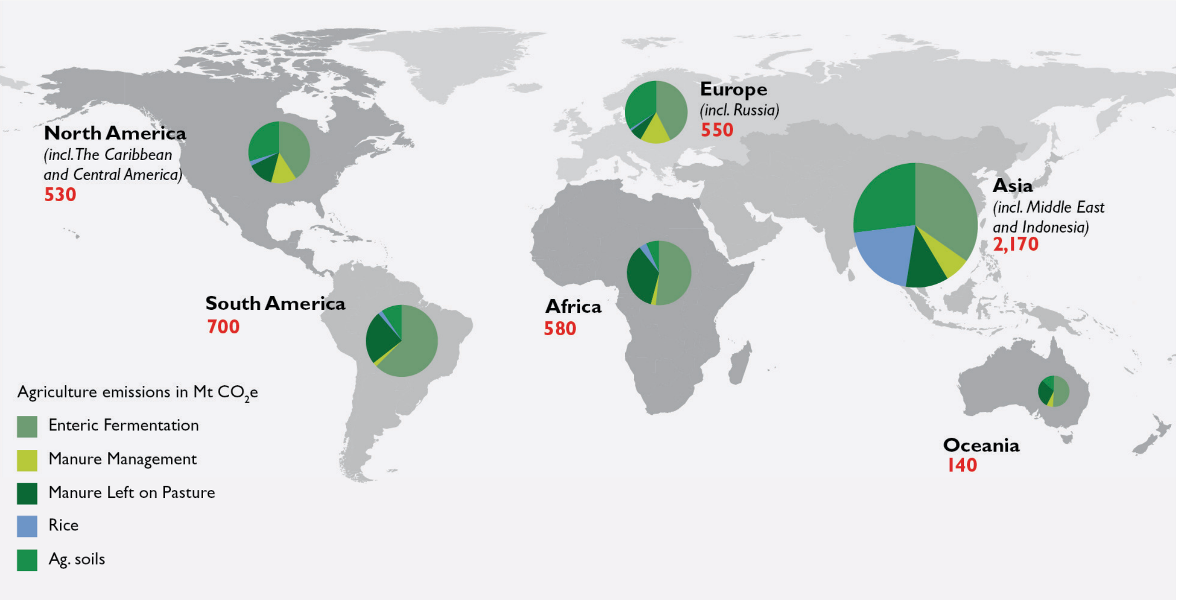
Source: CEA analysis based on: FAOSTAT 2008; Gerber et al., and personal communications with Paul West; Institute on the Environment, University of Minnesota.

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.

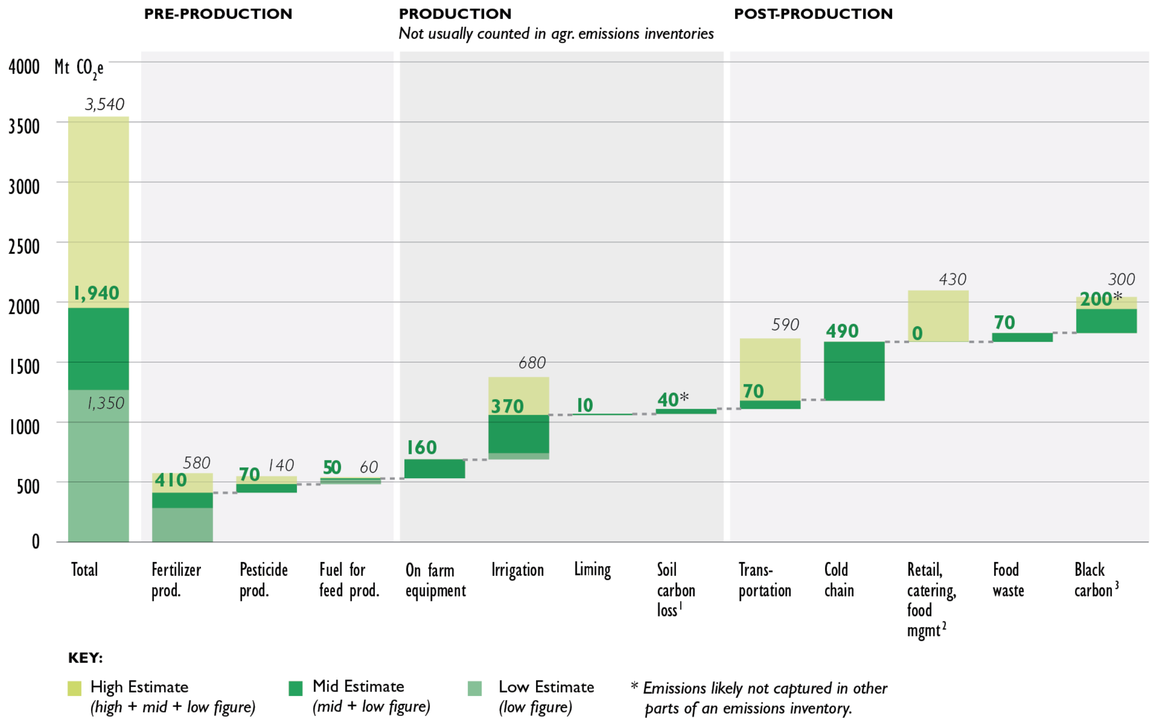
2.1.3 Supply chain emissions

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

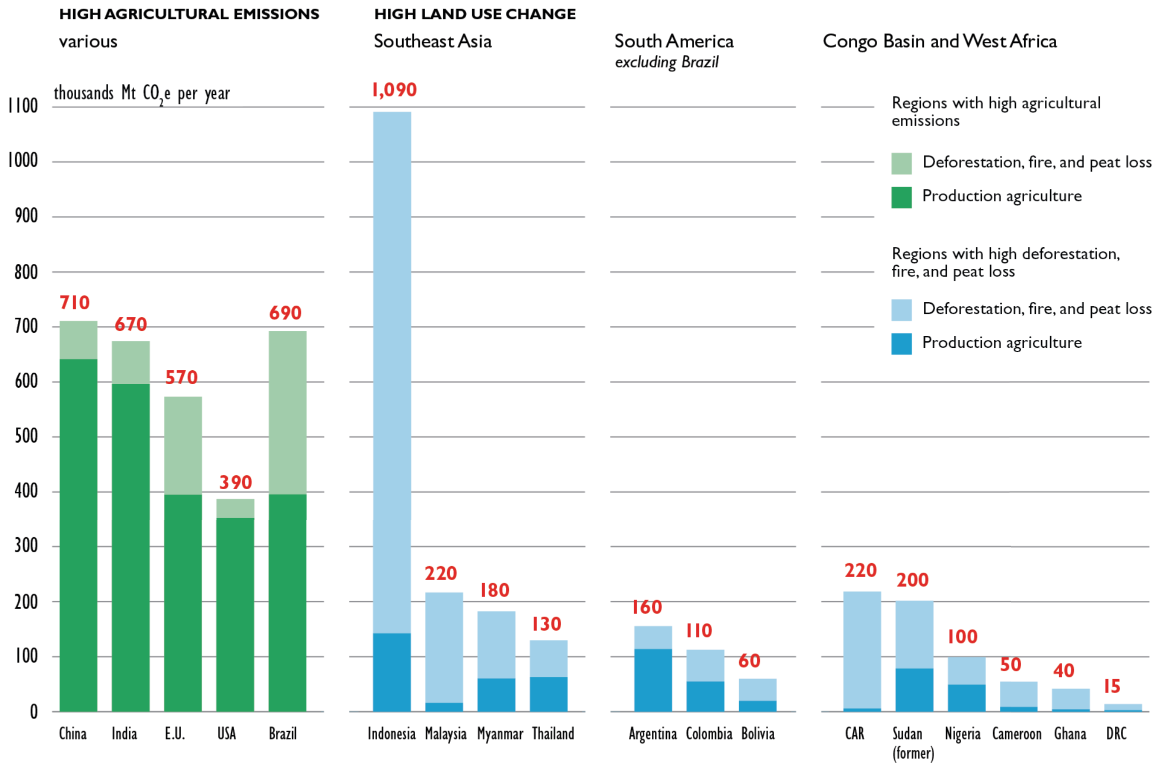
For the purposes of this report, ‘land use change emissions’ include deforestation, conversion of peatlands to agricultural lands, agricultural waste burning, and grassland and savanna burning. Together, this category emits between 3.5 and 7.8 Gt CO_2e per year.[18] Although the drivers of deforestation, 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 thorough discussion of the major opportunities, taking into account the economic, political, and social feasibility of interventions as well as the unique role of philanthropy.

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

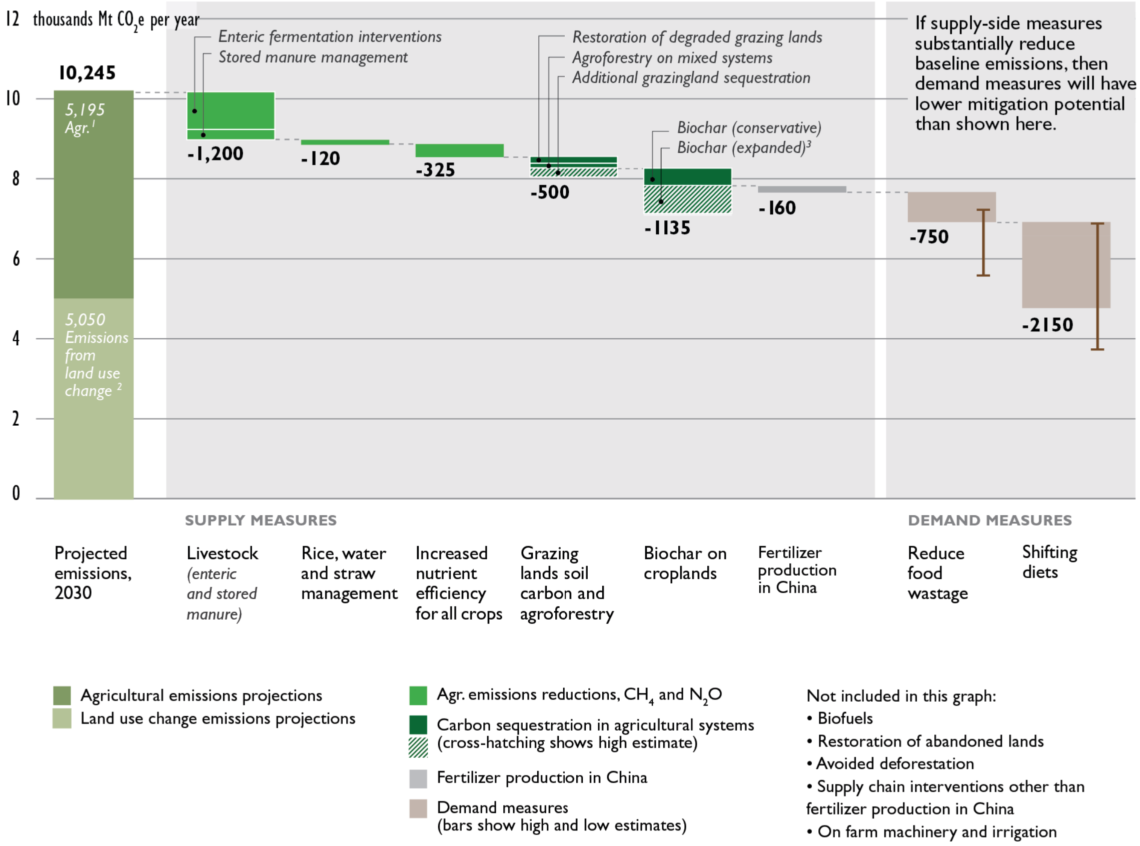
the mix of agricultural production, or major technological breakthroughs such as anti-methane vaccines for ruminants or crop breeding for nitrogen use efficiency.

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]



Not included in this graph:
- Biofuels
- Restoration of abandoned lands
- Avoided deforestation
- Supply chain interventions other than fertilizer production in China
- On farm machinery and irrigation

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

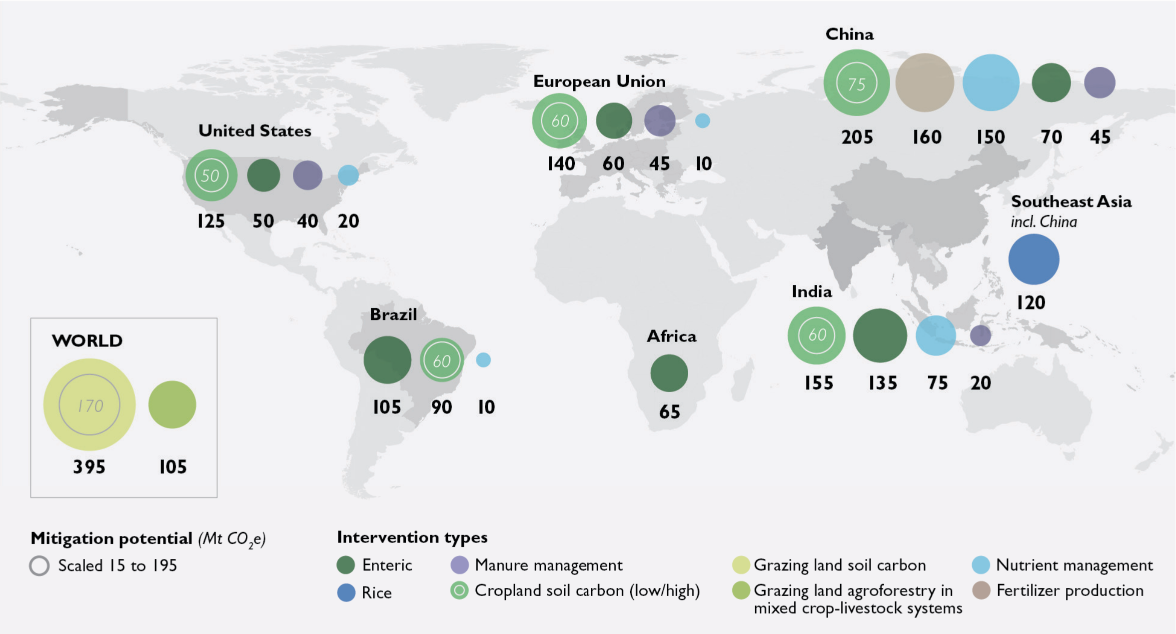
1. N_2O and CH_4 from direct agriculture, but not including methane from soils or fire emissions. Based on FAO emissions scaled by country and sector emissions growth factors predicted by EPA 2012.
2. Highly uncertain; estimated based on linear scaling of current ration of land use change/agriculture 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

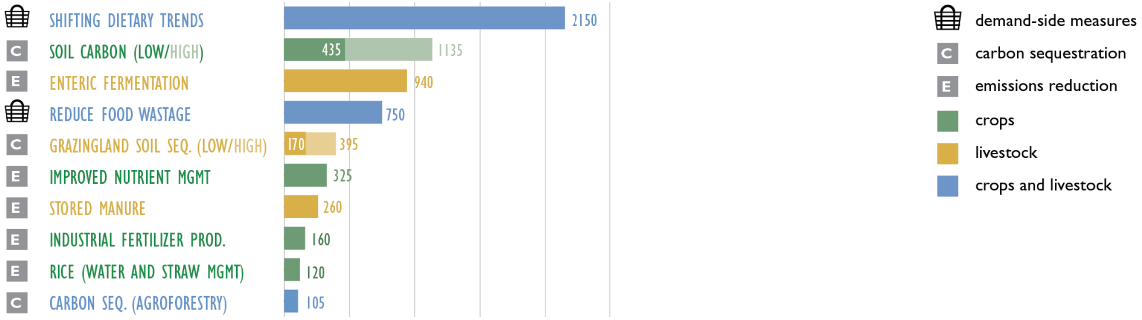
World

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$_2$e)



MITIGATION CATEGORY	REGION / COUNTRY	DETAILS

SHIFTING DIETARY TRENDS

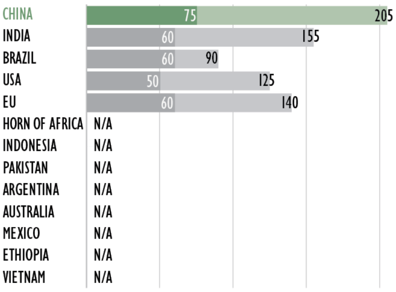
WORLD 2,150

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)

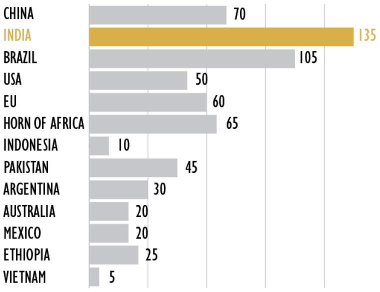


This report relies on an analysis of the mitigation potential from global adoption of biochar to provide estimates for soil carbon sequestration potential on croplands. Two estimates are shown, using different assumptions about available feedstocks and the inclusion of avoided emissions in the life-cycle 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



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 CO$_2$e 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).

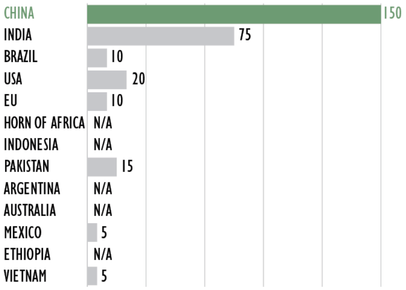
This report provides two estimates of mitigation potential from soil carbon sequestration in grazing lands, drawing from multiple sources in the scientific literature. The carbon sequestration potential of grazing lands is one of the most uncertain areas of agricultural mitigation. The lower estimate 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]

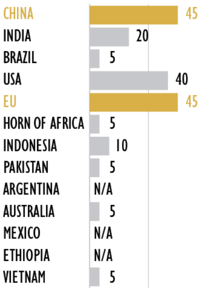
Sub-Saharan Africa: Most croplands across Sub-Saharan Africa receive too little fertilizer. Increasing rates of fertilizer use across the region would greatly benefit yields, without much of an increase in emission. With increased yields, higher volumes of crop residues would be available for soil carbon 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 160[iv]	**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 CHINA 25 INDIA 15 BRAZIL 0 USA 0 EU 0 HORN OF AFRICA N/A INDONESIA 10 PAKISTAN 5 ARGENTINA N/A AUSTRALIA N/A MEXICO N/A ETHIOPIA N/A VIETNAM 10	**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.

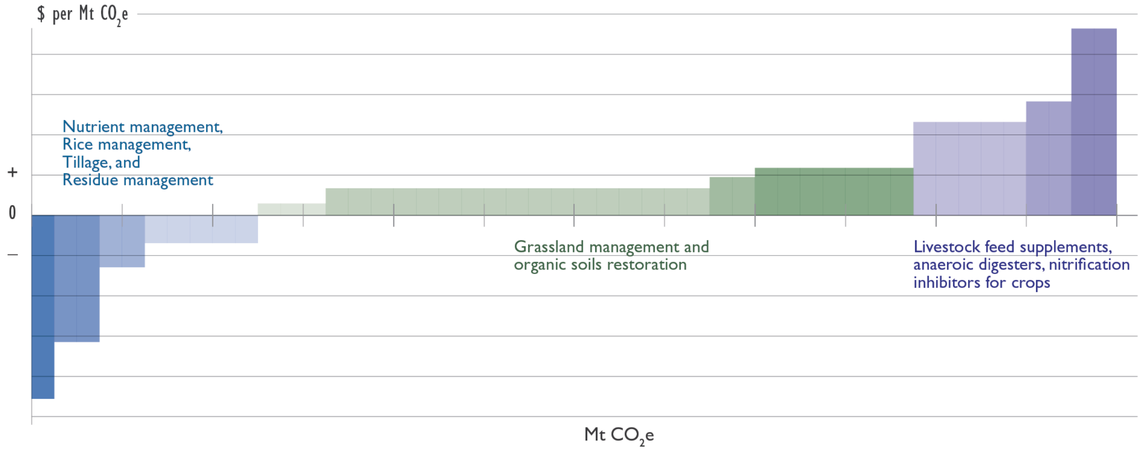
Mitigation options and costs will vary significantly by region due to a number of factors including: variation in local natural resources, the maturity of local markets and distribution chains, willingness of national and local governments to subsidize, promote, and regulate mitigation practices, and 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 #3

[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.

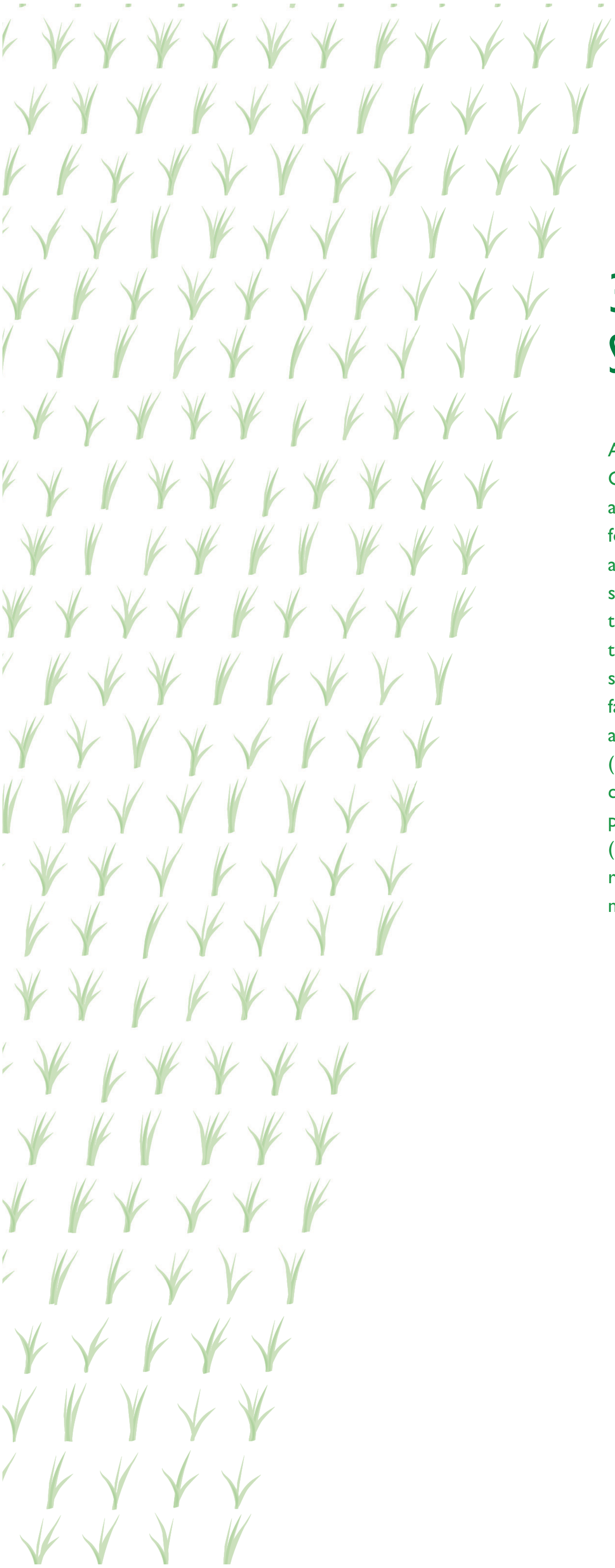
[27] Estimates based on CEA analysis. See Annex 3 for methodology and sources.

[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). Greenhouse *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

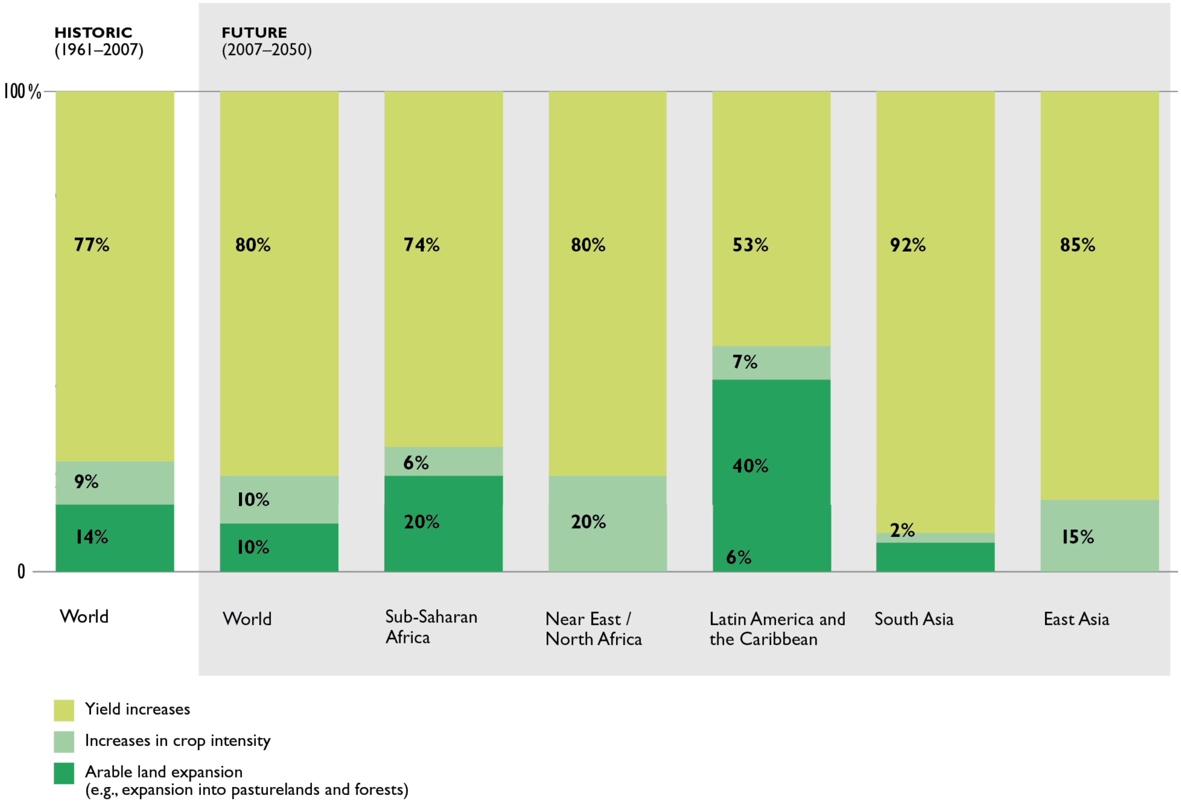
Co-benefits	Trade-offs
Food security Intensification can contribute to increased availability, stability and nutritional quality of food.	**Long-term Risks** Intensification can lead to structural vulnerabilities due to high dependency on modern inputs (e.g., agrochemicals, few varieties, and energy) 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.

Role of Philanthropy

Goal	Objectives	Interventions
Reduce GHG emissions through sustainable intensification	Promote realization of high mitigation intensification opportunities at scale	Assess mitigation effectiveness of intensification strategies in REDD+ finance Develop assessment tools to identify mitigation opportunities with high co-benefits and low / manageable tradeoffs

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Promote realization of high mitigation intensification opportunities at scale	Medium	Medium- to long-term	Low/Medium	Medium

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Promote realization of high mitigation intensification opportunities at scale

ASSESS MITIGATION EFFECTIVENESS OF INTENSIFICATION STRATEGIES FOR FINANCE RELATED TO ADDRESSING DRIVERS OF DEFORESTATION

As part of its REDD+ strategy and grantmaking, donors and philanthropy (e.g., CLUA) are promoting sustainable intensification to reduce agricultural expansion into forests. The mitigation potential of intensification depends on the emissions efficiency of new practices and on the increase in total production caused by its rebound effect. For example in Brazil, intensification of low-efficient cattle pasture can spare land for other crops and therefore reduce pressure on forests (see Section 3.3 on *Enteric Fermentation*). But while fertilizer application or the practice of liming increases pasture productivity, they also cause additional GHG emissions. And, once realized by ranchers, intensified cattle production presents a business case that in combination with increasing global demand for beef could trigger further expansion and deforestation. Therefore, this strategy could lead to a substantial increase in emissions from production (e.g., fertilizer, enteric fermentation) and land use change (e.g., deforestation), which could potentially offset mitigation benefits. The rebound effect—only due to price elasticities—could dramatically reduce the mitigation potential of intensification in developing countries.[8]

We therefore recommend reviewing, assessing and ensuring the mitigation effectiveness of intensification strategies in the context of REDD+ financing. This assessment would involve the organization of a strategic dialogue with non-governmental organizations (NGOs) and experts involved in implementing agricultural REDD+ strategies. In the context of such dialogue, one or several workshops could be organized to unite experts and implementation agencies in order to discuss synergies and tradeoffs across multiple environmental, social and ethical objectives of sustainable intensification.[9] Data and experiences could be compared with the view of formulating safeguards and assessment tools that allow philanthropy to assess the potential adverse effects of REDD+ activities focusing on agricultural drivers.

IDENTIFY HIGH-MITIGATION OPPORTUNITIES THROUGH THE DEVELOPMENT OF ASSESSMENT TOOLS

Departing from REDD+, where sustainable intensification in agriculture has emerged as a major strategy to curb deforestation and associated emissions, philanthropy could also support more general assessments that are based on tradeoff analyses[10] or economic modeling at various scales and timeframes that would map the complex implications of different intensification pathways, economic and institutional factors, and identify strategies to mitigate any tradeoffs. Such assessments could be undertaken in cooperation with interested donor organizations and support national governments. They could raise awareness on potential caveats of intensification for sustainable development and, as climate change is often secondary to most other objectives, philanthropies could play a particularly important role in promoting better integration of mitigation objectives. Eventually, this work could provide the basis for developing high-mitigation opportunities for intensification with optimized co-benefits and low or manageable tradeoffs.

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[9] See for example: Thematic Group on Sustainable Agriculture and Food Systems of the Sustainable Development Solutions Network. (2013). Solutions for Sustainable Agriculture and Food Systems – Technical Report for the Post-2015 Development Agenda. Paris, France: Sustainable Development Solutions Network. The report provides evidence-based indicators for sustainable development goals.

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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

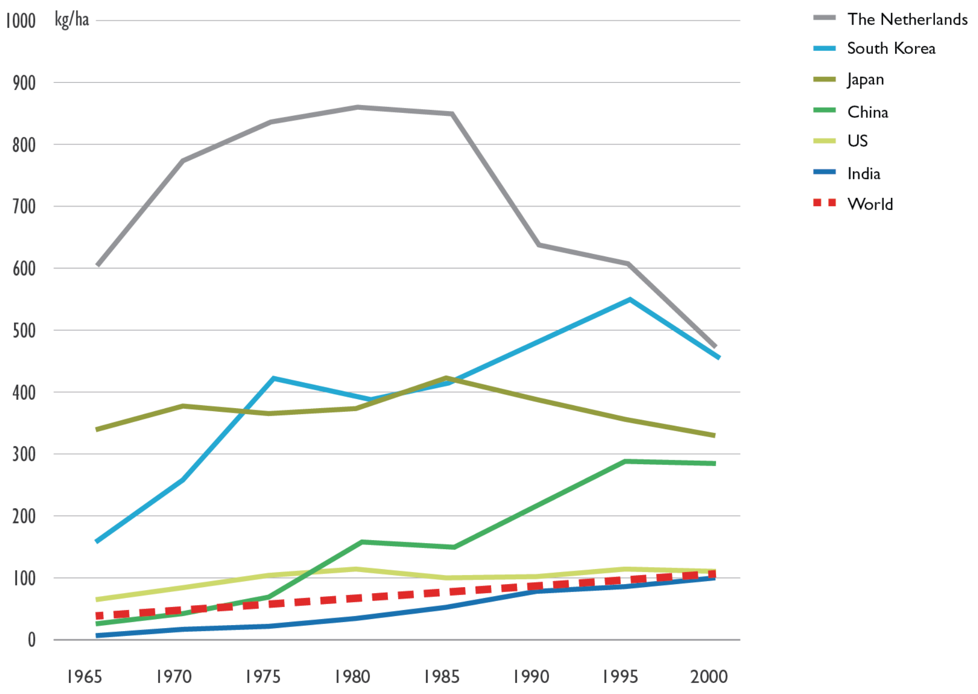
Co-benefits	Trade-offs
Cost savings Improving fertilizer application efficiency as well as improving industrial efficiencies in fertilizer production reduces capital costs.	Potentially reduced yields A perceived risk from farmers is that reducing nutrient applications could reduce yields. This is true 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]

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.[9] In 1982, more than half the national fertilizer output was produced by 1,227 small-scale factories. [10] 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.

Role of Philanthropy

Goal	Objectives	Interventions
Reduce GHG emissions from improved fertilizer management and production ~485 Mt CO_2e per year	Improve fertilizer use and management in China	Evaluate the Soil Testing and Fertilizer Recommendation program in China and additional measures to reduce fertilizer application
		Support efforts in knowledge dissemination to farmers on correct fertilizer management
	Improve fertilizer production in China	Engage the fertilizer industry through investment or outreach.

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Improve fertilizer use and management in China	150 Mt CO_2e per year	Medium term	Medium/High	Medium
Improve fertilizer production in China	160 Mt CO_2e per year	Short term	Low	Low

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Improve fertilizer use and management in China

ANALYZE STFR PROGRAM AND ADDITIONAL MEASURES TO REDUCE FERTILIZER APPLICATION

Food security is of paramount importance to the Chinese government. While this prioritization means that the Ministry of Agriculture is hesitant to adopt any nutrient management initiative that might threaten yields, the Ministry has embraced soil testing. Soil testing can help ensure the long-term fertility of the soils, which is clearly in the best interest of food production, and is also a foundational tool for efficient nutrient management practices.

The Soil Testing and Fertilizer Recommendation (STFR) program was launched in 2010 and is the main national program to address the problem of nitrogen fertilizer overuse and allow for improved targeting of applications. 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. Existing economic analysis suggests that fertilizer-reducing practices are labor-intensive, and that nitrogen fertilization rates are not responsive to changes in fertilizer subsidy or price levels, unless those subsidies were to be conditional on environmental outcomes.[11] One entry point for developing a program of work on fertilizer management would be to document STFR implementation modalities, assess the effectiveness of different implementation modalities, and identify the specific practices and conditions that contribute to reduced fertilizer use. A better understanding of what works at the local- and farm-level would help inform further improvements in policy delivery. This assessment could then be coupled with work on measures that can address the structural problems within the sectors and that serve as disincentives for reducing fertilizer use. Issues that can be addressed here are labor constraints, land tenure, land consolidation and barriers to application equipment use. These studies could be carried out with the respective Academies of Sciences in China, a collaboration which could potentially help to reduce some of the siloed research that has been conducted.

SUPPORT DISSEMINATION OF INFORMATION TO FARMERS ON CORRECT FERTILIZER APPLICATION

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. This could include the use of new media such as farmer-to-farmer extension via videos (see Digital Green[12]), sending specified recommendations via cell phones, providing information services via the internet, or setting up knowledge platforms and exchanges with agricultural sciences students. These knowledge-sharing platforms could also result in other creative solutions that could address some of the adoption constraints on the ground, such as labor exchanges or equipment sharing networks.

Improve fertilizer production in China

ENGAGE THE FERTILIZER INDUSTRY THROUGH INVESTMENT AND OUTREACH

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.[13] 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.[14] Benefiting from the existing models, methodologies and data, philanthropy could support the development of a fertilizer program under the CDM program of activities (CDM PoA) or scaling up existing efforts under a ‘nationally appropriate mitigation action’ (NAMA). Philanthropy could support the development of the preparatory studies; climate finance could most likely be mobilized through bilateral donors.

Additionally (or alternatively), philanthropy could support organizations that have engaged with the fertilizer industry and have identified entry points for making the sector more effective and environmentally friendly (e.g., Institute for Industrial Productivity).[15]

Supporting either advocacy or developing a GHG reduction program are effective ways to engage policy making and mobilizing finance. Furthermore, China is an exceedingly important market for the international fertilizer industry and will continue to be so in the future. Engaging relevant firms like Yara and the International Fertilizer Association (IFA) in this market to discuss how new application practices can be tailored to the Chinese context, and meet environmental and GHG emission reduction goals, will be instrumental in moving the sector in the right direction.

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

[4] Ju, X., Xing, G., Chen, X., Zhang, S., Zhang, L., Liu, X., Cui, Z., Yin, B., Christie, P., Zhu, Z., Zhang, F. (2009). Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proceedings of the National Academy of Sciences of the United Nations (PNAS)*.

[5] He, H., Zhang, L., Li, Q. *How to Reduce Non-point Pollution from Crop Production? The Case of Fertilization in China. Center for Chinese Agricultural Policy*. Data from FAO and World Bank.

[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.

[8] Sun, B., Zhang, L., Yang, L., Zhang, F., Norse, D., Zhu, Z. (2012). Agricultural Non-Point Source Pollution in China: Causes and Mitigation Measures. *AMBIO, 4, 1*370-379.

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[10] Ibid.

[11] Huang, W. (2011). Analysis of the policy causes of pollution from agriculture fertilizers and its countermeasures. *Ecology and Environmental Sciences, 2,* 193-198.

[12] Digital Green. (2013). Retrieved 2013-2014, from http://www.digitalgreen.org.

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

[14] Climate Focus data.

[15] Institute for Industrial Productivity. (2012). Retrieved 2013-2014, from http://www.iipnetwork.org.

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. The Brazilian government projects increases in production for all major commodities until 2022. 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.

India. 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. The country faces a steep rise in dairy demand, and there is a substantial gap in feed and fodder availability.[3] 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 and access to better-quality stover and other feed is therefore a priority.

Role of Philanthropy

Goal	Objectives	Interventions
Reduce GHG emissions from enteric fermentation through improved livestock diets ~940 Mt CO_2e per year	Improve grazing lands management in beef production in Brazil	Promote awareness and capacity of cattle ranchers through outreach and vertical integration of the supply chain
		Increase effectiveness of the ABC program to reduce agricultural emissions
	Improve feeding practices in dairy production in India	Increase adoption of improved practices by making a business case and supporting outreach campaigns to processors, producers and farmers

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Improve grazing lands management in beef production in Brazil	105 Mt CO_2e per year	Medium-term	Medium/High	Low
Improve feeding practices in dairy production in India	70 Mt CO_2e per year	Medium-term	High	Low

*Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Improve grazing lands management in beef production in 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)[4]—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.

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.

PROMOTE FARMERS' AWARENESS AND CAPACITY

We recommend the following avenues for communicating better practices and their business case to farmers, and directing them to the necessary technical support for improved grazing lands management:

Support outreach and capacity building efforts through producer associations.
Cattle rancher and breeder association such as the Brazilian Association of Zebu Cattle Breeders (ABCZ) and other farmers associations are engaged in capacity building initiatives to support improved productivity in cattle ranching. Building on these well-established rancher-to-rancher networks, we recommend that philanthropy support an outreach and capacity building campaign targeted at medium-scale farmers.

Support coordination between producers and companies in the supply chain.
While horizontal integration, or concentration in the processing and meatpacking sectors presents a potential entry point for targeting better practices in production, vertical integration, or coordination between producers and companies along the supply chain is still limited. It is unclear whether or not working with upstream producers to improve their practices is something that would be inherently beneficial to the major processors and meat packers. There are a number of voluntary private and public-private initiatives that focus on sustainable intensification of beef production as a way of reducing agriculture pressure on forests. An important initiative is the Brazilian Roundtable on Sustainable Livestock (GTPS), a national multi-stakeholder partnership between producer organizations, beef processors, meatpackers, NGOs, environmental organizations, retailers, and restaurant chains. Given the heterogeneity of the sector, and the challenges of consensus building (for example, on a standard for sustainable beef production), substantial commitments are limited. However, the roundtable provides an important platform for dialogue, awareness building, demonstration projects (members have already initiated several pilot projects), and increased coordination along the supply chain (e.g., for communicating the business case for improved practices). Philanthropy could further contribute by: 1) supporting the GTPS and strengthening its contribution to effective coordination along the supply chain; and, 2) assessing the potential for processing companies, meatpackers, and retailers (the concentrated parts of the industry) to disseminate knowledge and capacity, and to create demand for better grazing land management.[5]

INCREASE THE EFFECTIVENESS OF THE ABC PROGRAM TO REDUCE AGRICULTURAL EMISSIONS

Further strengthening funding efficiency and mitigation benefits of the Brazil's ABC program will help to reduce emissions from enteric fermentation *and* deforestation. ABC is a federal credit and capacity building initiative established in 2010 that supports the implementation of mitigation options. Farmers investing in mitigation options while complying with certain environmental requirements have access to credit at low interest rates (5 percent) and a prolonged repayment period. The program encompasses a wide range of practices aimed at sustainable intensification in the cattle sector. To date, the bulk of funding (roughly 80 percent in 2012/13) has been allocated to the 'recovery of degraded pasture,' which, as discussed above, can contribute to increased livestock productivity, increase carbon stocks in the grazing land soils, and free up land for other uses.[6] During a relatively short time span, the ABC program has achieved considerable progress. By April 2013, the program reached disbursements of USD 2.3billion. Though the ABC program represents a sizable investment, it is overshadowed by the USD 64billion of government funding to support the agriculture and livestock sectors without specific sustainability requirements at similar or slightly higher interest rates.

The Ford Foundation has commissioned several reviews of the ABC program,[7] which could serve as a factual basis for improvements to the ABC program, focused on both reduced land conversion and sustainable intensification of livestock production. The primary opportunities to improve the ABC are twofold:

- Expanding capacity of the program by advocating for a substantial increase in the share of loans, currently at two percent for most credit programs, that can be used for technical extension and,
- Advocating for private sector involvement in the ABC program or other relevant investment, primarily as a way to bring more capital to the effort through public-private partnerships. Participants might include private investment funds, private banks, extension service providers, and insurance companies.

Improve feeding in Indian dairy production

India faces a steep rise in dairy demand, yet there is a substantial gap in feed and fodder availability[8] and prices are increasing for both dairy products and feedstock. At the same time, productivity remains low, at roughly half the world average.[9] 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,[10] 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.

INCREASE ADOPTION OF IMPROVED FEEDING PRACTICES BY MAKING A BUSINESS CASE AND SUPPORTING AWARENESS CAMPAIGNS

The National Dairy Development Board (NDDB) has developed a National Dairy Plan (the Plan), a central government policy aimed at improved animal productivity, among other objectives. The Plan's implementation is supported by the World Bank through the National Dairy Support Project (2012–2017). This project includes a USD 258.3million component for improved breeding and feeding practices. Activities will be implemented through the cooperative system in 14 states. Activities relevant to improved feeding include: 1) extension services to farmers to support better-balanced feeding, based on a sophisticated Information Network for Animal Productivity and Health that gives farmers advice on the least cost ration for feeding; and 2) extension services and interventions to support fodder development, through activities such as seed production and silage demonstration activities.[11]

Although the National Dairy Plan addresses capacity building and improved market coordination, it is primarily focused on farmers in the cooperative system.[12] The cooperative system is a supply chain network which links millions of smallholders to processing facilities, market access, technical assistance, and veterinary services. The Plan is expected to reach about ten percent of the country's dairy animals. Philanthropy could amplify the government program by expanding outreach to farmers who are not included in cooperatives, such as farmers supplying milk to private processing companies, producing milk without further processing or without entering formal markets. Philanthropic efforts could reach these farmers through the following initiatives:

Support an outreach campaign targeting private dairy processing and feed producer companies to communicate potential benefits and business cases of improved feeding practices.
Activities could include workshops or dialogues between the private sector, the NDDB and public or private extension service providers. Potential partners and forums include the Indian Dairy Association, the Federation of Indian Chambers of Commerce and Industry, the Confederation of Indian Industry and companies already engaged in relevant activities.

Support a public awareness campaign targeted at rural dairy farmers to educate farmers about better feeding practices, the benefits of engaging in them, and available extension services.
Radio jingles in local languages, radio, and TV programs have proven effective in similar public outreach campaigns. For example, a similar campaign recently was successful in promoting animal husbandry as an additional source of livelihood for smallholders. *Krishi Darshan*, a well-established and popular Indian television program already provides agricultural education to rural farmers with a focus on improving productivity. The NDDB, other relevant institutions (e.g., *Krishi Vigyan Kendras*) and private companies could all be partners in this initiative.

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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 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.

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

[5] The Moore Foundation is already actively engaging with private sector actors to support sustainable intensification of beef production.

[6] Assad, E. (2013). *Agricultura de Baixa Emissão de Carbono: A evolução de um novo paradigma.* ABC Observatório.

[7] Ibid.

[8] 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.

[9] Working Group on Animal, Husbandry, and Dairying. (2013). *Report of the working group on animal husbandry & dairying 12th five year plan (2012-17).* New Delhi, India: Planning Commission Government of India.

[10] Goth, B. (2013). Dual-purpose maize could reduce fodder shortages in India. I*nternational Maize and Wheat Improvement Center (CIMMYT).* Blog post. Retrieved 2013-2014, from http://blog.cimmyt.org/?p=11595.

[11] The World Bank. (2012). *Project Appraisal Document of the National Dairy Support Project.* Washington D.C.: The World Bank.

[12] The Economist. (2012). "Verghese Kurien." *The Economist.* Retrieved 2013-2014, from http://www.economist.com/node/21563260.

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).

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 African is a prime example of such a location.

This report also provides two estimates of the global mitigation potential on grazing lands, as well as an assessment of the mitigation potential for agroforestry practices adopted by a limited set of agricultural systems, based on published literature. However, the data for both grazing lands management and agroforestry have a high level of uncertainty as well. 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.[15] 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.[16] 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.

This report relies on a global assessment of the mitigation potential from biochar, built upon Woolf et al. 2010, as a quantification of the mitigation potential from soil carbon sequestration on croplands.[17] This analysis calculates the net greenhouse gas benefits of a one-time application of 50 t C per hectare, of biochar produced in a 'modern' facility, based on a model of regionally available carbon feedstocks that do not have competing uses. We present two different mitigation estimates based on two different sets of assumptions about available feedstocks and boundaries of the lifecycle analysis of biochar. See Annex 3 for more details. Although we recommend support for development of biochar as a mitigation practice, our reliance on a biochar specific analysis should not be mistaken for either a lack of support for other carbon sequestration practices or an overly optimistic view of biochar. We were unable to provide a global assessment of mitigation potential from other conservation agriculture practices because due to lack of globally consistent and comprehensive data.

Given the data limitations, we have struggled 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.

Role of Philanthropy

Goal	Objectives	Interventions
Increase carbon sequestration in agricultural systems	Make the case for silvopastoral systems in Brazil	Initiate and support research and dialogue to establish better practices
		Support awareness campaigns targeted at producers to communicate best practice
	Increase below and above-ground carbon sequestration in agricultural systems in Sub-Saharan Africa (SSA)	Facilitate the development of methods and decision support tools for trade-off assessment
		Support scientific network to collect and analyze long-term data series of SSA soil carbon stocks and fluxes
	Support the development of biochar	Test and scale-up biochar production and use in key markets (e.g. China, Brazil).
		Enhance credibility and knowledge on biochar by promoting standards in biochar production

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Make the case for silvopastoral systems in Brazil	35 Mt CO_2e per year	Long-term	Medium/High	High
Increase carbon soil sequestration in SSA	Low	Long-term	Low/High	High
Support the development of biochar	50–205 Mt CO_2e per year	Long-term	High/Medium	Medium

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions[18]

Make the case for silvopastoral systems in Brazil

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. The active management of pasture complements the strategies recommended in Section 3.3 on *Enteric Fermentation* and is aligned with policy priorities (e.g., the ABC program supports an integrated crop-livestock-forestry system). Building on existing initiatives, such as the pilot projects supported by the Gordon and Betty Moore Foundation, the Brazilian Roundtable for Sustainable Livestock (GTPS), and major producer associations we further recommended:

INITIATE AND SUPPORT RESEARCH AND DIALOGUE

We propose the initiation and support of research and multi-stakeholder dialogues to establish better practices, business cases, and metrics for improved grazing land management and silvopastoral systems in Brazil. While some integrated grazing systems are emerging in Brazil and neighboring countries, the understanding of economic benefits of active pasture management is still limited. We therefore recommend analyzing the economic viability of these systems.[19]

SUPPORT AWARENESS CAMPAIGNS

We further propose supporting awareness campaigns targeted at producers to communicate best practices, [20] demonstrate the business case, and prove additional co-benefits of improved practices. In Brazil, the focus would initially be on medium-scale farms. However, managed grazing and agroforestry systems are also beneficial for small-scale livestock systems, and communications efforts could eventually evolve to target smaller actors as well.

Increase carbon sequestration in agricultural soils in Sub-Saharan Africa

Soils in Sub-Saharan agricultural systems are generally considered to have relatively low carbon contents both because of the characteristically weathered soil type and sub-optimal management practices. Regardless of the exact mitigation benefits of increased soil carbon sequestration practices, the synergies with existing agricultural development efforts across this region are high.

DEVELOP DECISION TOOLS TO ASSESS TRADE-OFFS

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.

However, while improved management of soil organic matter is generally in the long-term best interest of farmers because it supports long-term soil health, not all of the mitigation practices are in their economic interest, particularly for their short-term economic interest. For example, agroforestry systems, changes to forages or grazing intensities on pasture, increased use of perennials, and introduction of cover crops can all require an upfront investment that may not be possible for farmers without some kind of support or incentive. While there is a lot of attention to 'climate smart agriculture,' currently the initiatives and dialogues are fractured. These efforts need to coalesce into a unified and standardized agenda that can help direct resources in a more efficient and impactful manner.

One way to support these processes is the development of a decision support tool for donors, investors, and farmers that help decision-makers on all levels understand trade-offs and maximize long-term yields, economic returns, and GHG mitigation opportunities associated with their existing or planned agricultural programs, projects and investments. This tool needs to be practical, simple and user-friendly, country-specific, harmonized, and standardized.

DEVELOP LONG-TERM DATA SERIES FOR CARBON STORAGE

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,[21] 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. We propose creating a network of scientists and government organizations that support a coordinated effort to collect, analyze, and monitor the long-term storage of carbon in Sub-Saharan soils as well as to develop a soil typology database for the region. This network must be internally harmonized and standardized, as well as compatible with on-going efforts to build soil data sets in other regions.[22] The collected data would provide governments, development institutions, and NGOs essential scientific information. Ultimately, this information could support investments in improved soil carbon management practices, helping to increase production, sequester carbon, and mitigate greenhouse gases.

Support the development of biochar

Supporting the development of biochar as an effective mechanism for soil carbon sequestration is a worthwhile, if long-term, initiative for any agriculture-climate oriented foundation. 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.

TEST AND SCALE UP BIOCHAR PRODUCTION AND USE

The market for biochar has still not been proven. Though biochar provides yield increases in most farming systems, the yield increases do not always outweigh the costs of biochar to farmers, or require very long payback periods. The economics need to be evaluated on a case by case basis because yield response will vary greatly depending on both biochar and soil type, and costs can also vary greatly. In many cases, a price on carbon or other forms of subsidy will be necessary. Furthermore, biochar infrastructure is not well developed. Systems need to be in place to take biomass from the fields, to the processing facilities, and then back to the fields.

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.[23] 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. Working with Chinese partners to advocate for the testing of a subsidy on biochar would be a worthwhile way to further advance this technology.

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.

PROMOTE HIGH QUALITY BIOCHAR

The production of low-quality biochar is a challenge to the overall credibility of the product as well as to its potential to scale. The quality of biochar—both the amount of stable carbon in the biochar, and the stability of the stable carbon in the biochar—can vary dramatically, depending on feedstock and processing parameters. The International Biochar Initiative has developed standards for biochar as well as a certification program which is currently operational in the U.S. and Canada.[24] These standards should be promoted across the globe, and the certification program should be expanded.

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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. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds). Cambridge, 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

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

[16] Ibid.

[17] Woolf D, JE Amonette, FA Street-Perrott, J Lehmann, and S Joseph. (2010). Sustainable biochar to mitigate global climate change. Nature Communications 1, 56

[18] Additional recommendations for enhancing carbon storage in soils are made in Section 5.1 as part of subsidies reform.

[19] See for example, Landers, J. (2007). *Tropical Crop-Livestock Systems in Conservation Agriculture. The Brazilian Experience.* Rome, Italy: Food and Agriculture Organization of the United Nations, 2007.

[20] E.g., Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). (2011). Boas práticas agropecuárias: bovinos de corte: manual de orientações. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)

[21] 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.

[22] E.g., 1) In the U.S., the National Cooperative Soil Survey, anticipates soil maps and data available online for 100 percent of the nation's counties in the near future, 2) The Global Research Alliance on Agriculture and Greenhouse Gases is focusing on use of models, including the DNDC model, to potentially expand and create a global soil carbon monitoring network, 3) In the E.U., the Joint Research Center of the European Commission manages the European Soil Data Center.

[23] 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.

[24] International Biochar Initiative. (2014). Retrieved 2013-2014, from http://www.biochar-international.org.; Budai, A., Zimmerman, R., Cowie A., Webber, J., Singh, B., Glaser, B., Masiello, G., Andersson, D., Shields, F., Lehmann, J., Camps Arbestain, M., Williams, M., Sohi, S., Joseph, S. (2013). *Biochar carbon stability test method: an assessment of methods to determine biochar stability.* Westerville, OH: International Biochar Initiative.

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 opportunities and food security issues related to climate change and rice production.

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 (outlined in Section 3.2) 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 (see below).

Role of Philanthropy

Goal	Objectives	Interventions
Reduce GHG emissions from rice production ~ 120 Mt CO_2e per year	Scale up sustainable rice intensification systems that integrate climate mitigation.	Build a model for resource-use efficiency practices in rice production with proven mitigation effect; and scale up in ASEAN countries
		Build a mitigation component into food security projects on rice

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Scale up sustainable rice intensification systems that integrate climate mitigation	Low	Medium-term	Low/Medium	Medium-High

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Scale up sustainable rice intensification systems that integrate climate mitigation

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.

BUILD A MODEL FOR INCREASING RESOURCE USE EFFICIENCY

The International Rice Research Institute (IRRI) and partners are developing farming systems for increasing resource use efficiencies that reduce GHG emissions and identify associated incentives and policies that are needed. Individual countries spearheading mitigation efforts could act as role models for other countries who want to be seen as 'members in good standing' within the ASEAN community.

Support for piloting this model in countries, like Vietnam is needed and could be an entry point for philanthropy. Once documentation of how the model can work in a country is developed, it can be incorporated into high-level ASEAN discussions to be scaled up across its member countries. International agricultural development donors like the Bill & Melinda Gates Foundation and bilateral donors are already making significant investments into more efficient and sustainable rice production systems.

BUILD A MITIGATION COMPONENT INTO FOOD SECURITY PROJECTS ON RICE

Food security projects for rice, focusing on increasing yields and climate resilience represent major components of the dominant agricultural programs nationally and internationally. These projects and programs provide important services including: introduction and dissemination of new practices and higher yielding varieties, improving the capacity of forecasting for effective responses to demand fluctuations and climate shocks, identification of vulnerable geographic areas and population groups, the development and/or dissemination of climate change adaptation practices and various other objectives. GHG Mitigation methods already exist that can complement existing food security and resiliency projects. Philanthropy can support the incorporation of these practices more proactively into existing and newly developing food security projects and raise the sense of urgency to address both mitigation and adaptation components jointly where ever possible. It can also facilitate the development of working models, including building on the developed rice-mitigation model (previous intervention) to enhance the synergies that various practices can provide between adaptation and mitigation or address possible trade-offs that might arise between the two within existing farming systems.

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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. Additionally, because 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.

Role of Philanthropy

Goal	Objectives	Interventions
Reduce GHG emissions from stored manure in key countries ~ 150 Mt CO_2e per year	Reduce emissions from stored manure systems in China	Support spatial planning for industrial livestock facilities
	Reduce emissions from stored manure systems in the U.S.	Support biogas production subsidies in key states

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Reduce emissions from stored manure systems in China	45 Mt CO_2e per year	Short term	Low	Medium
Reduce emissions from stored manure systems in the U.S.	40 Mt CO_2e per year	Medium term	Medium	Low

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Improve manure management in China

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. In addition to the specific interventions listed below, general support for clean water regulations that cover non-point source pollution would greatly benefit China.

SUPPORT SPATIAL PLANNING FOR INDUSTRIAL LIVESTOCK FACILITIES

Support for spatial planning for industrial livestock production in China is an important near-term opportunity. Effective spatial planning will allow the effluent from large-scale facilities to have sufficient cropland available for field application without over saturation, while spatial concentration of these facilities could lock in manure pollution and GHG emissions. Planning tools to help determine nutrient budgets of CAFOs, nutrient requirements of crops, available land, and siting are needed.[6]

Improve manure management in the U.S.

SUPPORT BIOGAS PRODUCTION SUBSIDIES IN KEY STATES

In the U.S. there is generally an unfavorable regulatory climate for supporting economic viability of methane digesters. Improving the markets for bioenergy in a few key states could help scale up the use of methane digesters across the country. For example, state legislation or public utility regulations can include a carve-out for biogas from livestock manure in state level renewable portfolio standards and/or renewable fuel incentives. Key states for intensive livestock production (primarily pigs and dairy) in the U.S. include California, North Carolina, Wisconsin and Iowa. Philanthropy could play an important role in supporting advocacy efforts aimed at securing these kinds of production subsidies within key states and utilities.

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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).

[6] Ibid.

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	Facilitate 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.

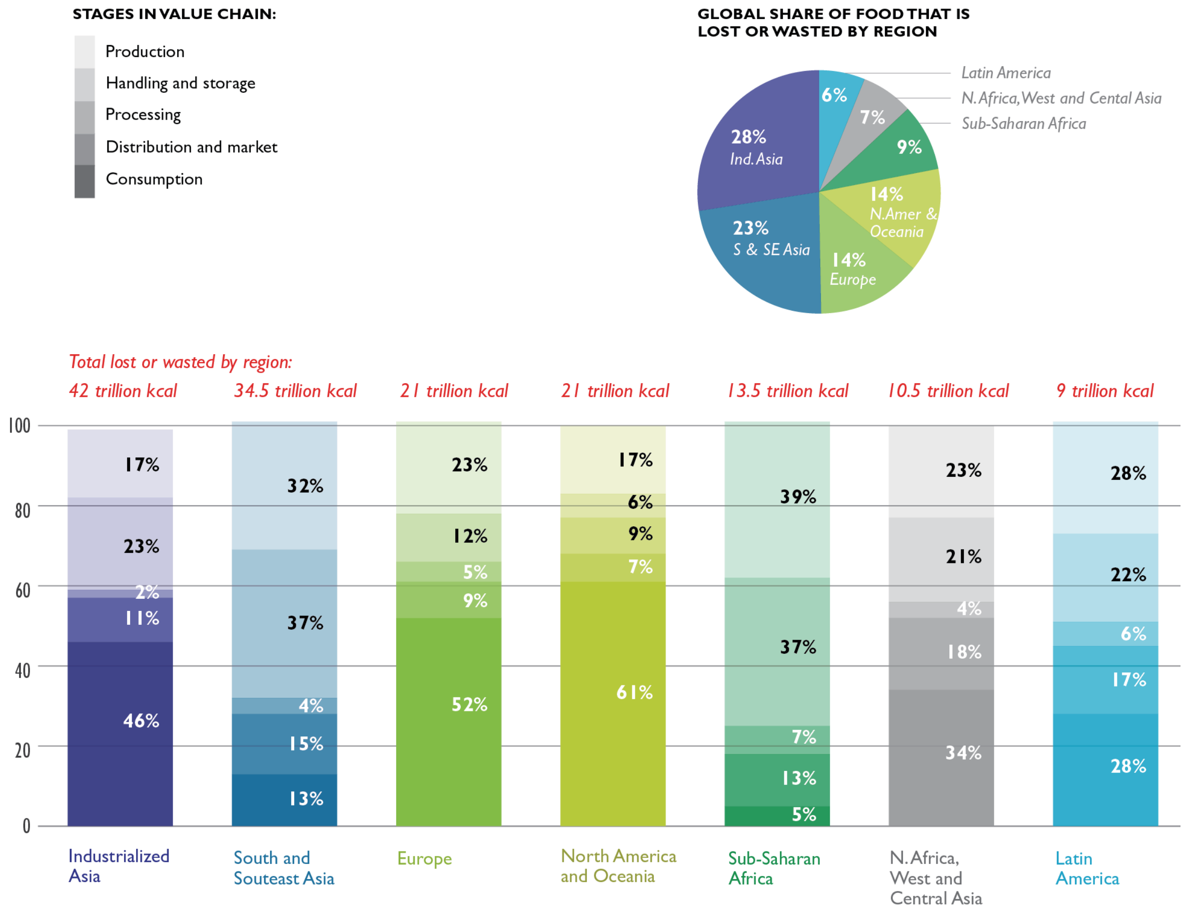
China and the U.S. appear to provide the largest opportunities for GHG mitigation from consumption practices.[12] In addition, policy makers, civil society and private sector actors in China and the U.S. have shown willingness to address this issue and implement interventions. Countries in South/ Southeast Asia, Europe and Latin America also provide opportunities, yet for comparatively smaller gains.

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.[15] In university canteens, one third of food purchased is wasted, and in urban residences, food waste has increased four-fold since the 1980s.[16] Government policies have been enacted that place restrictions on the use of government funds for wasteful banquets. 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.[17] Overconsumption and waste is usually due to shoppers not planning ahead, misunderstanding labels, and consumers and caterers serving large portion sizes. The U.S. government launched a national campaign called the U.S. Food Waste Challenge in June of 2013, calling for support from farmers, manufacturers, retailers and consumers to reduce food wastage in the country.[18]

Figure 14. Food waste by region and stage in value chain [19]

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



Source: FAO, 2013.

Role for Philanthropy

Goal	Objectives	Interventions
Reduce food wastage by 60% ~ 2 Gt CO_2e	Reduce consumer food waste in China and the U.S.	Revise food date labeling practices in the U.S. Support consumer education through communication campaigns
	Engage the private sector and reform corporate policies in China and the U.S.	Measure food waste in food companies along the supply chain
	Reduce food loss in the value chain by improving handling and storage practices in South/ Southeast Asia and Sub-Saharan Africa	Provide technical and financial support to farmers

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Reduce consumer food waste in China and the U.S.	High	Long term	Medium/High	High
Engage the private sector and reform corporate policies in China and the U.S.	Medium	Medium term	Low	Medium
Reduce postharvest by improving handling and storage practices in developing countries	Low	Long term	High	Medium

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Reduce consumer food waste in China and the U.S.

REVISE FOOD DATE LABELING PRACTICES IN THE U.S.

Labeling is placed on perishables (and some non-perishables) to provide consumers information regarding the freshness and safety of food. However, given the lack of federal standards, 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.[20] Food wastage can be reduced by streamlining and simplifying dates and labels through actions by manufacturers, retailers and the government. In 2013, Tesco, a U.K.-based grocery store, piloted the use of a single date code on its meat, fruit and vegetable products, ultimately resulting in reductions in food waste.[21] Similarly, the Japanese Ministry of Economy, Trade and Industry worked with 40 food retailers, producers and wholesalers to revise the labeling guidance document to facilitate consumer understanding.[22]

Philanthropy could fund initiatives that are seeking to establish a clear and consistent labeling system by engaging the food industry, the federal government and government agencies. The Natural Resources Defense Council (NRDC) and Harvard University's Food Law and Policy Clinic published a study[23] in September 2013 that outlines detailed recommendations on how to make the labeling system more coherent and uniform. Resources could be invested to apply some of the recommendations in the study and other similar initiatives, for example: 1) consumer research to determine what label communicates best to consumers; 2) meetings between NGOs/consumer organizations and industry to develop strategies and establish best practices; 3) consumer education around the meaning of dates; and 4) advocacy of policies/legislation for national, standardized system.

SUPPORT CONSUMER COMMUNICATION CAMPAIGNS IN CHINA AND THE U.S.

In China, in 2010, the State Council issued a *Notification on Strengthening Grain Saving and Opposing Waste* which promotes better practices to reduce harvest and postharvest loss, as well as consumer waste. Since 2013, President Xi Jinping has been vocal about reducing waste since 2013, calling for consumer and government measures to address the issue. 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 government and public campaigns including 'Clean Your Plate', and 'Operation Empty Plate,' could be leveraged and expanded with more resources. Food waste campaigns could take advantage of high-profile endorsements and increase awareness and incentivize behavior change through more targeted media and retail campaigns.

While communication campaigns could be effective, very little research exists for exploring approaches to influencing consumer behavior around food, especially in China. Before expanding media and outreach campaigns, funding research that identifies opportunities to influence food consumption behavior in line with cultural and social norms could be very useful. Understanding how to better influence practices in catering waste would be particularly helpful. Research could also identify additional national campaigns on food, health or the environment that may be leveraged, and allow for more effective engagement in China. For example, given China's serious water scarcity problem and the government's priority to address it, public information campaigns on saving water through reducing food wastage should be advocated. A study published in 2013[24] addresses food wastage and possible solutions in China, and was supported by the Ministry of Science and Technology of China and the National Natural Science Foundation of China, among others. These institutions along with Universities in China could be potential partners for additional research.

In the U.S., the government (Department of Agriculture (USDA) and Environmental Protection Agency (EPA)) recently launched the U.S. Food Waste Challenge, with the aim to improve practices of farmers, manufacturers, retailers and consumers. The USDA and the EPA are making commitments to reform policies that improve data, improve technology, improve consumer awareness and reduce waste in schools as well as other venues. The two agencies agreed to scale up a consumer education campaign being piloted in the Pacific Northwest called 'Food: Too Good to Waste' (FTGTW) that provides materials that individuals and community organizations can use to conduct a campaign. While these are all praiseworthy initiatives, consumer reach is still quite low and there is no dedicated funding to scale up the campaign nationally.

The U.S. Food Waste Challenge (and the FTGTW campaign) could be leveraged with NGO and retailer campaigns and expanded to a unified, national campaign promoted through social media, commercials, schools and universities and point of sale informational posters in supermarkets. Partnerships could be forged with municipalities, food companies, healthy eating/nutrition campaigns, schools, and compost haulers. In addition to the USDA and the EPA, active organizations and institutions on this issue include: Food Waste Reduction Alliance, NRDC, Feeding America, Johns Hopkins Center for a Livable Future, City of New York, Nestle, WRAP, James Beard Foundation, Overbrook Foundation, Fink Foundation, among others. Philanthropy investment may be effective in 1) expanding a national campaign and improving materials used (school curricula, templates for restaurants and grocery stores to use, etc.); and 2) establishing a coordination hub or dedicated organization that provides information and engagement platforms for all stakeholders wanting to get involved.[25]

Engage the private sector and reform corporate policies

MEASURE THE WASTE OF FOOD COMPANIES IN CHINA AND THE U.S.

Businesses can better manage waste that is measured and quantified. A business case for addressing waste can be made stronger by quantifying economic opportunities. WRI, in partnership with other organizations,[26] is developing a standardized protocol for auditing food loss and waste, the Global Food Loss and Waste Measurement Protocol. The Protocol seeks to harmonize measurement approaches, enable comparability and transparency (e.g., in reporting and disclosure), and establish an approach for countries and businesses to measure and monitor waste. The Protocol will support the FAO and UNEP food wastage initiatives and serve as a tool for better management of waste in the value chain. Supporting the outreach and application of the Protocol to Chinese and U.S. food companies and linking them to reporting platforms like the Carbon Disclosure Project could be an effective way of reducing wastage and emissions. Additional research is also needed to quantify how reducing food waste could influence the emissions bottom line for corporations.

Reduce food loss in the value chain by improving handling and storage practices

Methods including intensification and diversification of production, and the use of more effective handling and storage units could significantly reduce upstream food wastage in South/Southeast Asia, Latin America, and particularly Sub-Saharan Africa. Intensification and other production techniques are detailed in the supply-side sections of Chapter 3. 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.[27] 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.

EXPAND FINANCIAL AND TECHNICAL ASSISTANCE FROM GOVERNMENT AGENCIES AND AID PROGRAMS

Given 95 percent of agricultural research investment focuses on increasing crop production, investment in postharvest wastage remains largely overlooked. Increasing the share of investment in addressing postharvest losses can yield significant gains, especially as food prices rise. Depending on their size and focus, foundations may have a role to play in leveraging investments not only in agricultural research, but also in programs that increase technical and financial support for farmers in developing countries experiencing food wastage problems (e.g., Sub-Saharan Africa, South Asia and Southeast Asia). Support to farmers through enhanced extension services could raise awareness of these technologies and build capacity via farmer engagement and public service announcements. Smaller-scale finance from philanthropy may be leveraged with existing investments in agriculture by other donors or foundations (e.g., providing a trainer of trainers program). Foundations could also provide seed-grants, establish demonstration sites and facilitate procurement of materials. The African Postharvest Loss Information System (APHLIS) provides valuable information on where losses occur in Africa and may be used as a resource for prioritizing funding.

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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] Garnett, T. and Wilkes, A. (2014) Appetite for change: Social, economic and environmental transformations in China's food system. Food Climate Research Network.

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[16] Liu, J., et al. (2013). See fn #14

[17] 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.

[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

[20] 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.

[21] Lipinski, B. et al. (2013). See fn #5

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

[23] Natural Resources Defense Council (NRDC) and Harvard Food Law and Policy Clinic. (2013). See fn #20

[24] Liu, J., et al. (2013). See fn #14

[25] In the U.K, the organization WRAP has led work to reduce food waste by conducting research, creating and operating a consumer awareness campaign, and leading a joint business commitment. They act as a central hub and a convening body that coordinates all activities aimed at reducing food waste. In the U.S., a similar central hub would be beneficial to inform and provide assistance to all interested and relevant stakeholders.

[26] Partners include: FAO, UNEP, World Business Council for Sustainable Development, EU-FUSIONS, Waste Resources Action Programme (WRAP), and Consumer Goods Forum.

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

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 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]

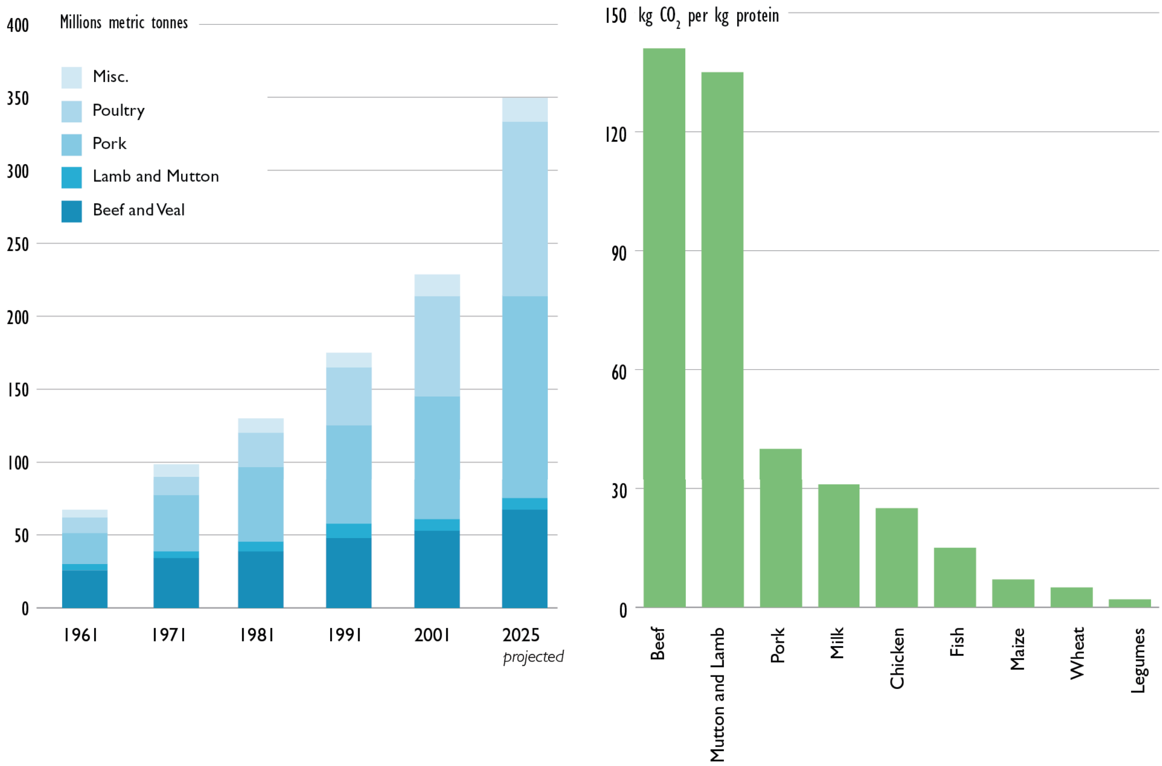
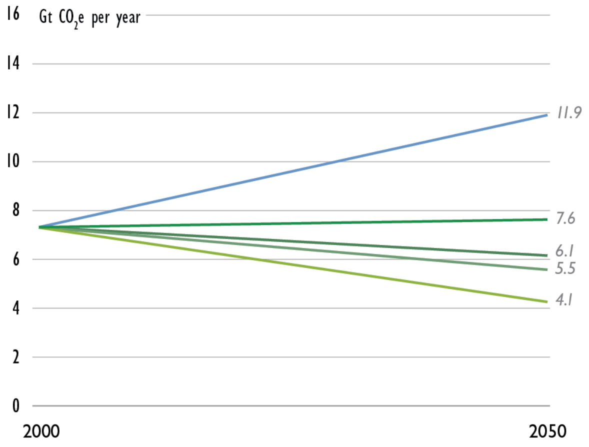


Figure 15 Source: Adopted from FAOSTAT and Elam, 2006.
Figure 16 Source: Gonzalez et al., 2011.

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. However, we recommend focusing on only two countries at this stage given the fairly new and untested nature of the interventions.

China. 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 are 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.[18] 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.[19] However, red meat still represents the largest proportion of meat consumed (58 percent).[20] 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.[21] National campaigns including Meatless Mondays have also been adopted widely since its inception, with schools, universities, government agencies and restaurants successfully raising awareness and encouraging people to reduce their meat consumption.[22]

Role of Philanthropy

Goal	Objectives	Interventions
Reduce meat consumption, primarily of beef, to healthy levels of consumption ~2.15 Gt CO_2e per year by 2030	Influence domestic policies in China and the U.S. to reduce demand	Leverage existing food and resource security policies to reduce beef production and imports, and promote alternative proteins in China
		Promote public health policies that incentivize healthy diets and healthy levels of protein intake in the U.S.
	Curb future demand of beef in China and decrease per capita meat consumption in the U.S. through media and outreach campaigns	Expand national campaigns and promote health links in the U.S.
		Build argument and enhance communications campaigns in China

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Influence domestic policies in China and the U.S. to reduce demand	High	Medium-term	Low/Low	High
Curb dietary trends through media and outreach campaigns	High	Long-term	High/High	High

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Influence domestic policies to reduce consumption of ruminants

LEVERAGE FOOD AND RESOURCE SECURITY POLICIES IN 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.[23] 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.[24] 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. Any policy initiative that could threaten its pork industry would likely not be looked upon favorably by the Chinese government. While focusing on pork is unlikely to be a fruitful approach, beef may be a more viable focal area. Given the resource constraints that China faces, including rural labor, land and water shortages,[25] it may be in its best interest to actively keep beef production to a minimum, and curb demand by limiting beef imports.

Traditionally, Chinese per capita beef consumption has been low because of cultural preferences for pork and poultry, however, western influence combined with income growth and urbanization have significantly increased demand in the last couple of decades.[26] Other scholars attribute increased beef production to policy changes that have made producing beef more profitable because of subsidized feeds.[27] While the need for shifting away from beef diets are well established for health and environmental reasons, there have been very few studies investigating effective interventions and evidence for sustaining change in dietary behavior, particularly in China. Many Chinese food choices, for example, are highly influenced by food safety issues related to, among others, antibiotics, packing conditions and the bird flu epidemics. Since studies are lacking on this topic, now may be an opportune time to commission a study that clarifies animal source food trends, particularly of beef, builds a case in China and explores culturally relevant intervention strategies in more detail. Philanthropy may also support studies that assess economic and food security impacts of increased beef consumption and production to inform agriculture and import policies in China including agriculture targets, tariffs, taxes on imports and subsidies on feed for beef. The Institute for Agriculture and Trade Policy has recently published a series of studies that explore China's feed, pork, poultry and dairy sectors and their future trajectories and impacts.[28] The Food Climate Research Network also recently published a report exploring social, economic and environmental transformations in China's food systems. These may be good platforms to explore the beef industry.

PROMOTE HEALTHY DIETS IN PUBLIC HEALTH POLICIES IN THE U.S.

Health concerns are a leading driver of decreased beef consumption in the U.S. There is a suite of public health related policies set at the federal or sub-national level that have the potential to directly or indirectly influence consumer behavior. These policies include proliferating nutritional standards/guidelines, providing curriculum on saturated fats in meats via public authorities (e.g., Department of Health and Department of Education), and applying these curricula to school and government cafeterias, the military, dieticians/ nutritionists, and health centers to encourage healthier dietary choices. Influencing the policies of these organizations to promote healthy meat choices and consumption levels could be a great point of leverage. For example, standards and curricula could promote substitution of red meat for healthier types of protein. They could also reflect the Institute of Health recommendations of ~ 58g of meat per day to reduce average U.S. daily consumption of 126g[29] by at least half. Policies could also be considered that use financial instruments, including 'getting the price right' fixes and taxes/subsidies that incentivize healthier and more sustainable meat products in the Farm Bill. Philanthropy may have a role in funding 1) meetings between NGOs/consumer organizations, research institutions and government to develop strategies and establish guidelines; and 2) advocacy initiatives to adopt policies and measures by federal and local governments to promote healthy diets.

Media campaigns and outreach to consumers

Changing consumer behavior and consumption patterns is a difficult task. It is often a slow cultural process. However, influencing consumer behavior through media and educational campaigns has been widely employed in the public health field to promote healthy diets and deter drug use, and experiences can provide useful lessons. The Drink Milk campaigns in the Netherlands and the U.S. have been particularly successful. It should be noted, however, that there have been very few evaluation studies on the effectiveness of policies affecting diets over time.[30] When evaluating how to intervene with behavioral trends in diet, the primary drivers of meat consumption and its context need to be understood and considered.

EXPAND EXISTING CAMPAIGNS TO INCREASE IMPACT IN THE U.S.

In the U.S., 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). Increasing consumer education of the health benefits of eating less meat can therefore influence a change in dietary habits. There is currently no government-led campaign, however, the Meatless Monday campaign, launched in 2003 by the Johns Hopkins School of Public Health to promote healthier diets, has grown significantly with consumer awareness reaching 50 percent in the U.S.[31] The campaign has been promoted by restaurants, large food caterers like Sodexo, some government agencies and media companies like Women's Health and Food Network, and has been successful in influencing consumers with 36 percent of those aware of the campaign saying that it has influenced their decision in reducing meat consumption.[32] Expanding this campaign or leveraging other existing healthy diets campaigns to include reducing meat, especially red meat consumption, would be a way to increase impact. Philanthropy could have a role in funding 1) expanded centralized campaigns through enhanced communication, social media outreach, grassroots efforts and partnerships with NGOs, chefs, universities and food caterers; and 2) meetings and conferences to discuss and promote best practices and latest information on initiatives to reduce meat consumption.

BUILD THE ARGUMENT AND ENHANCE COMMUNICATIONS IN CHINA

While there are currently no known meat reduction campaigns in China, there are anti-obesity and successful environment-related diets campaigns like anti shark-fin and tiger wine. Before launching a campaign, it would be apt for philanthropies to commission a study that clarifies animal source food trends and explores culturally relevant intervention strategies in more detail. This may be combined with the study mentioned in the domestic policy intervention above. Studies that investigate pathways for sustaining change in dietary behavior are largely lacking, particularly in China. Cultural levers will be needed to successfully shift consumer behavior and trends. For example, Chinese tend to prefer pork and seafood, are very price sensitive, are concerned about water shortages, and care enormously about food quality and safety. In addition to these socio-economic and cultural preferences, there are others that could be leveraged to curb an increased demand of ruminants. In addition to research, Philanthropy may also explore piloting communications campaigns by building on and expanding existing efforts like Meatless Mondays and WildAid's "5 to do today" to China. The Meatless Monday campaign has expanded to 29 countries via grassroots efforts and is currently being implemented in Taiwan and Hong Kong. The "5 to do today" campaign is looking to expand to China and asks consumers to do 5 things that will reduce their impact on climate change. Other activities could include 1) establishing a centralized hub and website that provides information to international stakeholders;

and 2) creating fellowships for Chinese public health and environmental advocates to study the potential of reducing meat consumption in the country.

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[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.

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[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.

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[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.

[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.

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

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[19] 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.

[20] 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.

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

[22] Ibid.

[23] 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.

[24] 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.

[25] Garnett, T. and Wilkes, A. (2014) Appetite for change: Social, economic and environmental transformations in China's food system. Food Climate Research Network.

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[30] Keats, S., and Wiggins, S. (2014). *Future Diets: Implications for agriculture and food prices*. London: Overseas Development Institute (ODI).

[31] FGI Research. (2012). See fn # 21

[32] Ibid.

5.

CROSS-CUTTING STRATEGIES

No one single strategy or recommendation can address the full mitigation potential of the agricultural sector. This suggests that a coordinated philanthropic 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.

Role of Philanthropy

Goal	Objectives	Interventions
Create international incentives for GHG reduction and removal	Incentivize GHG mitigation through subsidies reform in the U.S. and the E.U.	Establish financial incentives for soil management in the U.S. and the E.U.
		Protect, strengthen and expand conservation programs supported through the U.S. Farm Bill
		Support farmer advisory programs in the U.S. and the E.U.
	Remove barriers and create incentives for GHG mitigation under the WTO and UNFCCC	Support a formal or informal process to examine the trade and clime change interface in the WTO

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Subsidies reform in the U.S. and the E.U.	No estimates	Medium-term	Medium/Medium/High	n.a.
Remove barriers and create incentives for GHG mitigation under the WTO and the UNFCCC	No estimates	Medium-term	Low	n.a.

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Incentivize 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:

ESTABLISH FINANCIAL INCENTIVES FOR SOIL MANAGEMENT IN THE U.S. AND THE E.U.

Given that emissions from agricultural soils are a major source of emissions both in the E.U. and the U.S., (see Section 3.4 on *Carbon Sequestration*), the possibilities to develop stronger incentives for soil management measures and for the protection of carbon-rich agriculture areas should be carefully examined. Appropriate incentives could enhance the long-term productivity of soils and facilitate coping with the future effects of climate change. Any measure should be combined with a cost-effective carbon measuring and monitoring system for agricultural soils.[6]

Text Box 3: Rising Agricultural Subsidies in Developing Countries[7]

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.

STRENGTHEN CONSERVATION PROGRAMS IN THE U.S.

To shift the U.S. agricultural subsidies towards an agricultural model that considers climate and other environmental impacts would require strengthening and expanding conservation programs supported by the U.S. Farm Bill. Current conservation programs offered by the Farm Bill provide financial and technical assistance or easements for certain environmentally conscious efforts. However, programs often do not provide sufficient financing to cover all the costs of installation and the implementation of conservative measures. Proposals such as a reduction in the amount of crop insurance and emergency crop relief funds available to farmers would free up funds for more incentive programs that encourage climate-smart practices in the U.S.

SUPPORT FARMER ADVISORY PROGRAMS IN THE U.S. AND THE E.U.

There is also a need to improve awareness of climate change aspects among farmers and other rural actors on climate-conscious management, and to improve technical knowledge and guidance on appropriate measures for climate change mitigation at farm level. Currently, there is little use of rural development funds for the setting up and use of farm advisory services.

Enhance climate change action and reduce conflict potential between WTO and UNFCCC

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.[8]

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.[9] 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.

SUPPORT CLIMATE CONSIDERATIONS UNDER THE WTO

We recommend supporting a formal or informal process to examine opportunities and challenges for trade and climate change at the WTO. In parallel with their efforts to conclude the Doha Development Round, WTO members could be invited to a process that examines the potential impact of emerging domestic policies designed to combat climate change on trade. This process could also explore possible areas of conflict and ways in which WTO rules may be clarified and possibly amended to facilitate effective climate mitigation policies. Even if such a process were formally launched under the WTO, they would not require a new institutional framework or mandate. Paragraph 32 of the Doha Ministerial Declaration already instructs the Committee on Trade and Environment (CTE) to pay particular attention to the effect of environmental measures on market access, the relevant provisions of the Agreement on Trade-Related Aspects of Intellectual Property Rights and labeling requirements for environmental purposes.

The Declaration calls for this work to include the identification of any need to clarify relevant WTO rules and asks the CTE to make recommendations, where appropriate, with respect to future action, including the desirability of negotiations. This mandate could provide a formal space to address controversial trade and climate change issues in a non-negotiating setting. A formal process under the CTE would allow Parties to initiate deliberations on issues such as those mentioned above. In these areas, members could also assess whether the WTO rule book is properly equipped to deal with potential conflicts or whether existing disciplines need to be clarified or amended.

As a step towards informing and laying the groundwork for such a formal process, it would also be beneficial to add a climate and agriculture chapter to the existing *e15 Initiative*, a multi-stakeholder dialogue process aimed at identifying a set of policy options in response to current issues facing the multilateral trading system. The *e15 Initiative* is a four-year project designed to deliver a set of key outcomes at critical junctures. Throughout the process, the expert groups are in contact with WTO officials and member countries. They also engage with partner institutions that are responsible for co-managing the groups' work. By mid-2014, the expert groups will convene a multi-stakeholder dialogue and deliver outcomes on an agenda that follows up on the WTO Ministerial Conference in Bali. Finally, the *e15 Initiative* will provide options for the multilateral trading system at 2025 to carry into the following Ministerial Conference and the celebrations of the WTO's 20th anniversary in 2015.

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[2] Blandford, D and Josling, T. (2009). *Greenhouse Gas Reduction Policies and Agriculture: Implications for production Incentives and International Trade Disciplines.* Geneva: International Centre for Trade and Sustainable Development and International Food and Agricultural Trade Policy Council.

[3] Ibid.

[4] Bureau, J., Laborde, D., Orden, D. (2012). *U.S. and E.U. Farm Policies: the Subsidy Habit.* Washington, D.C.: International Food Policy Research Institute.

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

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[6] For the E.U. see: http://ec.europa.eu/agriculture/climate-change/pdf/sec2009_1093_en.pdf.

[7] 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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5.2
FINANCE AND INVESTMENTS

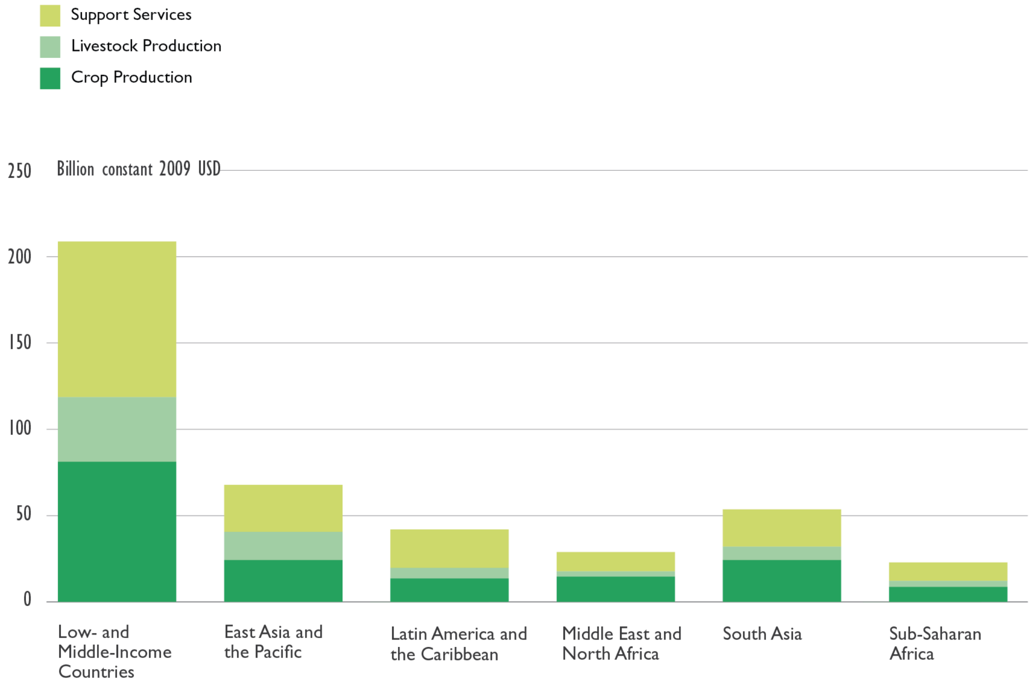
Background

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.

Role of Philanthropy

Goal	Objectives	Interventions
Steer international public funds into low-emissions agriculture	Reduce GHG impact of internationally financed agricultural progams	Steer donor support away from high emitting agricultural activities, especially beef production
		Include GHG data in investment appraisal and program evaluation
	Channel climate finance towards agriculture	Incorporate climate-smart agriculture in design and implementation of the Green Climate Fund

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Reduce GHG impact of internationally financed agricultural progams	No estimates	Medium-term	Medium/Low	Low
Channel climate finance towards agriculture	No estimates	Medium-term	Low	Low

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

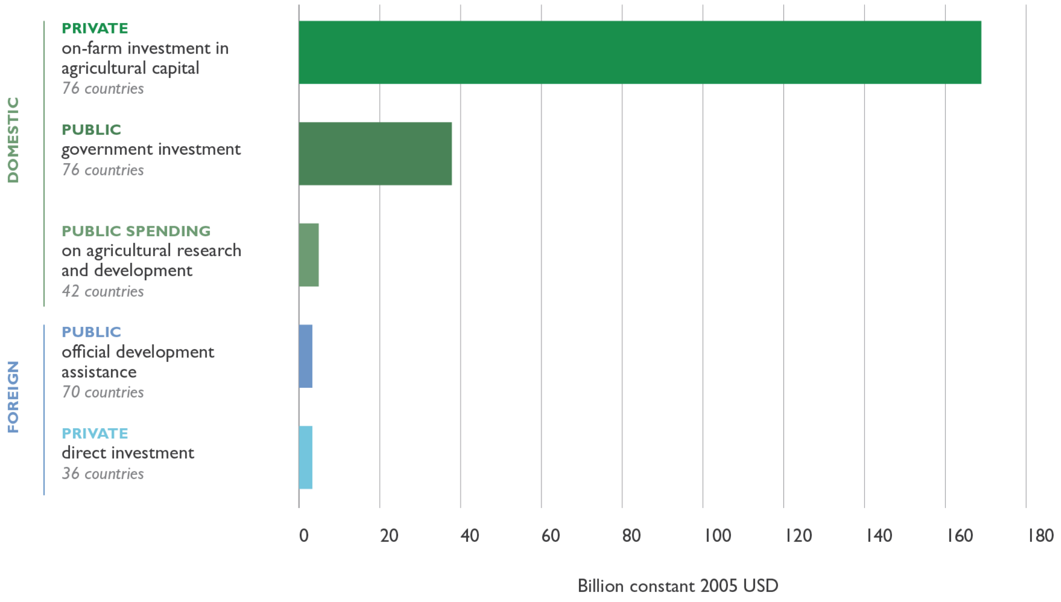
Reduce GHG impacts of internationally financed agricultural programs

The lion's share of agricultural capital 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.

STEER ODA TOWARDS LOW-EMISSIONS AGRICULTURE

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.

We suggest a review of public funding programs and a prioritization of projects and programs that incorporate climate-smart agriculture and limit high GHG intense practices. This prioritization could shift financing incentives away from projects like cattle livestock production and towards lower carbon agriculture projects, such as chicken, grain, and vegetable production, or even towards direct mitigation-related projects such as biochar facilities or irrigation systems that can enable mid-season drainage for rice production.

Educating financial institutions on the negative health and climate impacts of certain practices (like excessive meat production and consumption) may be an effective way to change the behavior of institutional, bilateral and multilateral investors. Similar to the pressure exercised on donors to withdraw from financing coal-fired power plants, NGOs could launch campaigns against beef financing by involving major health institutions and academics. Campaigns could be supported by studies that illustrate the costs of unhealthy diets and environmental degradation within unsustainable agricultural practices.

INCLUDE GHG DATA IN ODA APPRAISAL AND IMPACT EVALUATION

Multilateral banks, bilateral donors and private investors should also be encouraged to include GHG impact assessments in their project appraisal and monitoring and evaluation frameworks. Such integrated assessments at the level of decision-making around individual projects can drive low-carbon investments.[12]

Appraisal: The World Bank has already indicated an interest in assessing the carbon impact of its projects in project appraisal. However, tools that would allow such an assessment do not currently exist. Philanthropy could collaborate with the World Bank to develop such tools. While methodologies are still being developed and additional data collected, qualitative indicators that use default emissions values relating to particular agricultural systems and practices could serve as a rough guide for the appraisal of agricultural investments.

Monitoring: Furthermore, the World Bank and the International Finance Corporation (IFC) could be targeted as the potential first organizations to monitor the GHG impact of their agricultural investment portfolio. The shift of monitoring and evaluation in the World Bank from assessing implementation to tracking results provides an opportunity to include GHG impacts in the monitoring frameworks of the World Bank. Results-based systems build upon and add to traditional implementation-focused systems which emphasize project outcomes. One challenge will be the absence of baseline data. The starting point for building such data sets is the collection of information about existing and future agricultural investments, which could also enable countries to improve and target their agricultural policymaking.

Channel climate finance flows into agriculture

INCORPORATE CLIMATE-SMART AGRICULTURE IN THE GREEN CLIMATE FUND

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. The rules, procedures and methodologies applied by the Green Climate Fund are also likely to serve as benchmarks for other funders and private investors.

Agriculture is receiving a small share of climate finance. Despite representing between 10 to 25 percent of global emissions, agriculture received only 2.5 percent of fast-start climate finance.[13] 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 powerful force in unlocking significant agricultural mitigation potential.

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[1] United Nations Conference on Trade and Development. (2009). *World Investment Report: Transnational corporations, agricultural production and development.* Geneva: United Nations Conference on Trade and Development.; HighQuest Partners. (2010). *Private Financial Sector Investment in Farmland and Agricultural Infrastructure.* (No. 33). Paris: Organisation for Economic Cooperation and Development Food, Agriculture and Fisheries.

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[2] Foresight. (2011). *The Future of Food and Farming Executive Summary*. London: The Government Office for Science.

[3] United Nations Conference on Trade and Development. (2009). See fn #1

[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.

[12] Cochran, I., Morel, R. (2013). *Seeing the forest from the trees: Infrastructure Investment and "systemic" GHG impacts Lessons from the Keystone XL.* (Climate Brief No. 30).

[13] Climate Focus research and data.

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.

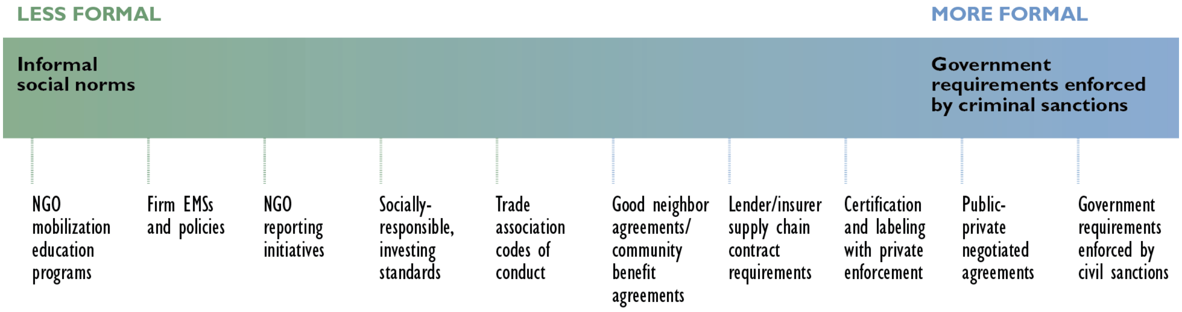
Voluntary principles. In December 2013, Sustainable Agriculture Initiative (SAI) published voluntary principles for sustainable beef farming, which were endorsed by major market actors, including McDonalds and Unilever. The SAI is a global food industry organization with the objective to facilitate initiatives 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.

Role of Philanthropy

Goal	Objectives	Interventions
Incentivize GHG reduction in agricultural supply chains	Strengthen climate change mitigation effectiveness of certification systems	Make the business case for certification Embed climate change mitigation in certification systems Advocate for government engagement in sustainable sourcing Mobilize support of certification with farmers
	Support vertical integration of supply chains	Reach out to traders and engage them in supply chain efforts

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Strengthen climate change mitigation effectiveness of certification systems	No estimates	Short term	Low/Low/Low/Medium	n.a.
Support vertical integration of up-stream stages of supply chains	No estimates	Long-term	Medium	n.a.

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Strengthen climate change mitigation effectiveness of 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. Philanthropy could support these objectives through the following activities:

MAKE THE BUSINESS CASE FOR CERTIFICATION

Philanthropy could further strengthen mitigation objectives in agricultural supply chain initiatives by identifying potential opportunities, leverage points, business cases and other success factors to maximize mitigation impacts of supply chain initiatives along with other sustainability objectives.[9]

EMBED CLIMATE CHANGE IN INTEGRATED CERTIFICATION SYSTEM

Climate change mitigation needs to be better integrated into existing certification systems and consolidated with standards along a multi-dimensional concept of sustainability. Such an integrated approach would replace the existing piece-meal approach towards certification with a more integrated system.[10] Harmonization, integration, and systematization of different schemes would reduce costs for participating companies and increase transparency and trust with consumers. Philanthropy could facilitate this approach by convening relevant stakeholders and developing pathways towards integration of GHG metrics in certification system as well as harmonization among systems.

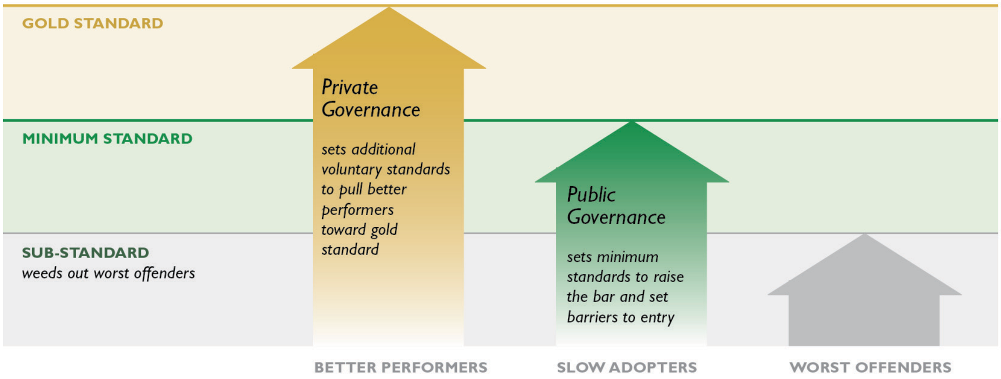
ADVOCATE FOR GOVERNMENT ENGAGEMENT

Though they are not mandated by governments, certifications, labeling schemes and other voluntary sustainable sourcing initiatives are influenced in various ways by government action. Public policy and regulatory action shapes the environment from which they emerge. The private sector may act to avoid mandatory standards or react in response to incentives. Voluntary certification can set high standards for leading performers, while regulatory measures can target the most damaging offenders unlikely to be reached by market-driven initiatives (see Figure 22).[11] To understand constraints and opportunities better, philanthropy could fund a study that reviews potential policy measures governments could adopt to increase demand for certified products. Such study should go hand in hand with an assessment of the legal context of such measures (e.g., trade law, state aide). An advocacy strategy could be devised based on this assessment.

MOBILIZE SUPPORT FOR CERTIFICATION WITH FARMERS

Farmers are entrepreneurs and will improve farm-level efficiency when it is good business. They will adopt sustainable agriculture practices on their farms as long as they believe in the business case and have access to the capital and the non-financial resources required for implementation. However, farmers will be reluctant to adopt practices that reduce emissions without reducing costs, will shy away from high upfront costs, and will not engage in the reporting of emissions without a clear understanding of the direct benefit.[12] Farmers in developing countries will also often lack knowledge about mitigation practices and need additional training and capacity building. Incentives for the adoption of new practices could come via procurement priorities, higher purchase volumes, or longer-term contracts. Philanthropy could support industry efforts by working with companies committed to reducing GHG emissions throughout supply chains by extending efforts to products in developing countries where additional training of growers is necessary. Tools that have been developed and can be applied by farmers in an industrialized context, such as the Cool Farm Tool or the COMET-FARM tool, could be adapted to the developing country context and piloted for particular commodities and countries. Financial support for the sharing of best practices and the benchmarking across comparable farming systems and farms would also be useful.

Figure 22: Examples of public versus private governance roles in sustainable supply chain initiatives[13]



Source: RESOLVE, 2012.

Support vertical integration of up-stream stages of supply chains

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. Philanthropy could support an outreach and advocacy campaign targeted at international trading corporations either directly or through NGO advocacy, for example commodity traders including Archer Daniels Midland Company, Bunge Limited and Cargill. Partners could include international NGOs such as Greenpeace, WWF, or multi-stakeholder dialogues.

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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.

[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 .

[6] Denef, K., Paustian, K., Archibeque, S., Biggar, S. & Pape, D. (2012). *Report of Greenhouse Gas Accounting Tools for Agriculture and Forestry Sectors*. Fairfax, Virginia: ICF International.

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

[8] De Man, R. (2013). Sustainable Sourcing of Agricultural Raw Materials - a Practitioner's Guide. *Sustainable Brands.*

[9] Such assessment could be built on existing work funded by CLUA member foundations, such as the comprehensive State-of-Knowledge Assessment of Standards and Certification in 2012, co-funded by the David and Lucile Packard Foundation.

[10] Denef, K. et al. (2012). See fn # 6

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

[12] Common Fields. (2011). *Unearthed: Agricultural Emissions in the Corporate Supply Chain: Findings from the CDP 2011 U.S. Agriculture Supply Chain Pilot*. London: Carbon Disclosure Project.

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

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., the 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.

Role of Philanthropy

Goal	Objectives	Interventions
Increase traceability and monitoring of GHG emissions from agricultural systems	Measure GHG emissions from agricultural sources	Develop GHG monitoring frameworks in in developing countries Develop simple on-farm monitoring tools
	Increase the traceability of GHG emissions along the supply chain	Support the development of robust emissions tracking systems across supply chains
	Facilitate the assessment of the impact of investments on GHG emissions	Develop tools that allow investors to assess the GHG impact of their investments

Overview of Objectives

Objectives	Mitigation potential in Mt CO_2e per year	Time to achieve objectives	Cost of implementation of the intervention	Uncertainty and MRV challenges
Measure GHG emissions from agricultural sources	No estimates	Medium- to Long-term	High/Low	High
Increase the traceability of GHG emissions along the supply chain	No estimates	Medium-term	Low	High
Assess impact of investments on agricultural emissions	No estimates	Medium-term	Low	High

* Methodology and quantification of table is detailed in Annex I

Recommended Interventions

Measuring GHG emissions from agricultural sources

DEVELOP GHG MONITORING FRAMEWORKS IN DEVELOPING COUNTRIES

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.[10] We therefore recommend the establishment of a scientific network that would bring together research on the particular practices across various farming systems, the biophysical and social conditions associated with the system, and the emissions the system generates. This characterization would allow for the better targeting of mitigation activities in tandem with the other objectives (e.g., food security, environmental or social) for the particular system. The data could also provide the basis for supporting integrated monitoring efforts across environmental and agricultural variables for better decision support to policy makers. This information could then also feed into improving country specific emissions factors, activity data and modeling and for establishing the newly required Biennial Update Report, in which all countries will need to establish GHG inventories and report on mitigation.

DEVELOP SIMPLE MONITORING TOOLS

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. Philanthropy could support the development of such tools.

Tracking emissions in supply chains

DEVELOP A GHG PROTOCOL TO TRACK 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,[11] 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[12]). We therefore recommend supporting the development of a protocol that allows the tracking of GHG emissions from source to consumer. 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[13] 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. Nevertheless, the development of tools that can be used by farmers and down-stream business partners remains a complex challenge. We therefore recommend developing a first protocol for a pilot commodity that is either comparatively easy to track from grower to end-user to be selected, or where existing efforts can be strengthened. Performance benchmarks (see above) could help costs remain within reasonable limits.

GHG reporting for investors

DEVELOP GUIDANCE AND METHODS TO ENABLE GHG REPORTING

Philanthropy could also support the development of tools that enable financial institutions and portfolio investors to accurately, consistently, and transparently report on the impacts from their investments. 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 (production and value chain) 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. The use of the relevant methods and methodologies, including associated costs, will have to be carefully considered.

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[1] Olander, L., Wollenberg, E., Tubiello, F. and Herold, M. (2013). Advancing agricultural GHG quantification. *Environmental Research Letters, 8.*

[2] Scholes, R.J., Palm, C.A. and Hickman, J. (2013). *Agriculture and Climate Change Mitigation in the Developing World.* South Africa: Council of Scientific and Industrial Research.

[3] Ogle, S., Buendia, L., Butterbach-Bahl, K., Breidt, F., Hartmann, M., Yagi, K., Nayamuth, R., Spencer, S., Wirth, T., Smith, P. (2013). Advancing national greenhouse gas inventories for agriculture in developing countries: improving activity data, emissions factors and software technology. *Environmental Research Letters, 8.*

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

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

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[10] Scholes, R.J. (2013). See fn #2

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6.

FINAL REMARKS

This report details 12 strategies and 41 interventions for philanthropy to address climate change mitigation in the agricultural sector. Considering that donors may plan their strategies based on themes, intervention type, and/or geographies, this final chapter highlights the various interventions based on these groupings and notes overlaps and synergies between the strategies.

MAJOR THEMES

Two common themes throughout the report include 1) addressing beef production and consumption, and 2) intensification and increased efficiency in the agricultural value chain. Livestock accounts for roughly 70 percent of agricultural emissions, the majority of which comes from beef production. Intensifying beef and reducing demand has substantial potential to reduce emissions, avoid forest conversion, increase carbon sequestration in grazing lands and improve human health.

Through increased efficiency, production is increased, waste decreased, and natural resources are spared, creating genuine win-win solutions which can increase food security and reduce emissions. However, intensification carries significant risks and needs to be carefully managed according to each type of agricultural system.

Beef

- **Enteric fermentation**—intensify beef production through improved feed and grazing management in India and Brazil
- **Financing low carbon alternatives**—reduce donor support of high emitting agricultural activities, especially beef production
- **Food wastage**—reduce food waste, especially of animal products
- **Manure management**—reduce emissions from stored manure systems in China and U.S.
- **Shifting diets**—reduce demand for beef in China and U.S.
- **Soil carbon**—improve grazing land management in Brazil

Intensification and Efficiency

- **Enteric fermentation**—intensify beef production through improved feed and grazing management in India and Brazil
- **Fertilizer**—increase efficiency of application and production of fertilizer in China
- **Food wastage** —increase efficiency of the value chain and reduce losses in Sub-Saharan Africa
- **Rice**—build a model for increasing resource using efficiency practices that integrate mitigation and adaptation for adoption in ASEAN countries
- **Soil carbon**—increase carbon sequestration in agricultural systems in China, India, Brazil, U.S., E.U. and Sub-Saharan Africa
- **Sustainable intensification**—produce more food on less land, using sustainable practices through effective policy and implementation instruments

TYPES OF INTERVENTION

There are three main points to leverage along the agricultural value chain which are highlighted in the recommended interventions; 1) Farmers and industry, 2) Consumers and 3) Government and public policy. Farmer and industry outreach is an efficient approach for gaining support and effecting change in production and supply chain practices. Consumer outreach is generally more costly; however it can be very effective, especially in influencing demand. Influencing public policy will be necessary to correct perverse policies and market forces, as well as provide incentives for sustaining low carbon agricultural practices. In addition to the identified leverage points, providing relevant and compelling research and tools to support outreach and policy reform is an important type of intervention.

Farmer and Industry Outreach

- **Enteric fermentation**—promote awareness of best practices and improve capacity of cattle ranchers in Brazil and India
- **Fertilizer**—support efforts to increase farmer knowledge on correct fertilizer application, and engage the national and international fertilizer industry to adopt improved production practices in China
- **Food wastage**—measure food waste in food companies along the supply chain in U.S. and China, and improve financial and technical support to farmers in SSA
- **Soil carbon**—support awareness campaigns in Brazil targeted at producers to advocate best practice
- **Subsidies and trade**—set up advisory services for farmers in U.S. and E.U.
- **Supply chains**—reach out to traders and support vertical integration of supply chains

Consumer Outreach

- **Reducing food wastage**—expand education on consumer food waste in China and the U.S.
- **Shifting diets**—curb meat consumption trends, especially beef through media and outreach campaigns in China and the U.S.

Influencing Public Policy

- **Enteric fermentation**—increase effectiveness of the ABC program in Brazil to reduce emissions
- **Finance**—reduce donor support of high emitting agricultural activities, especially beef production; include GHG data in investment appraisal and evaluation; and ensure consideration of agriculture in the Green Climate Fund
- **Food wastage** — revise food date labeling in the U.S.
- **Manure**—support biogas production subsidies in key states in the U.S., and support CAFO spatial planning in China
- **Tracking emissions**—develop tools that allow investors like the World Bank to assess GHG impact of their investments
- **Rice**—build a model for increasing resource use efficiency practices and advocate for scale up across ASEAN countries through policies

- **Shifting Diets—**advocate for food security policies in China to reduce beef production and imports, and promote public health policies that reduce meat (beef) consumption in the U.S.
- **Subsidies**—create incentives for agricultural mitigation via subsidies reform in the U.S. and the E.U.; expand conservation programs in the U.S. Farm Bill; and support the process to remove barriers and create incentives for agricultural mitigation under the UNFCCC and WTO

Research and Tools

- **Fertilizer**—evaluate the STFR program in China and additional measures to reduce fertilizer application
- **Food wastage & Shifting diets**—research culturally appropriate consumer intervention strategies and evidence for sustaining change in consumer dietary behavior in China
- **Tracking emissions**—develop simple on-farm monitoring tools; support development of emissions tracking systems across supply chains; and develop GHG monitoring frameworks in developing countries
- **Soil Carbon—**support scientific network to collect and analyze data series, and facilitate decision support tools in Sub-Saharan Africa
- **Sustainable intensification—**develop assessment tools to identify mitigation opportunities and manage tradeoffs

GEOGRAPHY

Based on mitigation potential and political/social feasibility, the five main geographies for interventions are Brazil, China, the European Union, India, and the United States. In addition, Sub-Saharan Africa and ASEAN countries are also highlighted given many philanthropy organizations have programs in those regions.

Brazil

- **Enteric fermentation**—intensify beef production through grazing management, increase effectiveness of the ABC program
- **Soil carbon and agroforestry—make the case for silvopastoral systems and** improve grazing land management through an awareness campaign targeted at producers; and support research to establish better practices

China

- **Fertilizer**—increase efficiency of application and production of fertilizer through research of the STFR program; enhanced capacity and awareness of farmers on application; and engagement of fertilizer industry on production
- **Food wastage**—support consumer outreach campaigns on food waste; and measure food wastage along the supply chain
- **Manure**—reduce emissions from stored manure systems through spatial planning for industrial facilities
- **Shifting diets**—support consumer outreach campaign; research culturally appropriate consumer intervention strategies and evidence for sustaining change in consumer dietary behavior; and advocate for food and water security policies to reduce beef production and imports
- **Soil Carbon**—support biochar development and use through carbon finance, and enhance credibility of biochar by promoting standards in production

European Union

- **Finance**—reduce donor support of high emitting agricultural activities, especially beef production
- **Subsidies**—create incentives for agricultural mitigation via subsidies reform, and set up advisory services for farmers

India

- **Enteric fermentation**—outreach to processors, producers, and farmers to improve feeding practices in dairy production

United States

- **Manure**—reduce emissions from stored manure systems by advocating for biogas production subsidies

- **Diets**—promote public health policies that reduce meat (beef) consumption, and expand consumer outreach campaigns
- **Food wastage**—revise food date labeling in the U.S. and expand consumer outreach campaign
- **Subsidies**—create incentives for agricultural mitigation via subsidies reform and expand conservation programs in the U.S. Farm Bill
- **Finance**—reduce donor support of high emitting agricultural activities, especially beef production

Sub-Saharan Africa

- **Food wastage**—reduce postharvest losses by improving financial and technical support to farmers to increase adoption of efficiency practices and technologies
- **Soil carbon**—support scientific network to collect and analyze data series, and facilitate decision support tools

ASEAN countries

- **Rice**—build a model for increasing resource use efficiency practices that integrates mitigation and adaptation and advocate for scale up across ASEAN countries through policies

ANNEX

ANNEX 1.
METHODOLOGY FOR OBJECTIVES OVERVIEW TABLES

Objectives

Relates to the objectives pursued with the proposed interventions in each section.

Mitigation potential Mt CO_2e per year

Drawn from own analysis and quoted sources as detailed in Chapter 2. Where there are no exact numbers due to lack of data/analysis, a level on a scale is indicated whereby:

- Low refers to GHG emission reductions of an estimated <100 Mt CO_2e per year
- Medium refers to GHG emission reductions of 100–500 Mt CO_2e per year
- High refers to GHG emission reductions of an estimated >500 Mt CO_2e per year

Time to achieve objectives

Relates to the estimated time spent between the initiation of a project or the making of relevant grants and the achievement of the stated objective, whereby:

- Short refers to <2 years
- Medium refers to 2–5 years
- Long refers to >5 years

Cost of implementation of the intervention

Relates to the estimated funds philanthropy would need to make available for the realization of the intervention and achievement of objectives, whereby

- Low refers to estimated costs of <USD 2.5million
- Medium refers to estimated costs of = USD 2.5–7.5million
- High refers to estimated costs of >USD 7.5million

In some sections we suggest one intervention to achieve the objective; in other cases we suggest several interventions to achieve the objective. These interventions come at different costs and are indicated accordingly for each intervention (e.g., Low/Low/High). In many cases they build on each other; in others they are independent. Generally, analyses and work with few, targeted stakeholders is less costly than research programs or broader campaigns. We estimate the costs being low where our recommendation is focused on a single analysis or very targeted, already well-defined activity (e.g., support a new e15 working ground under the WTO; develop a NAMA for the Chinese fertilizer industry; lobby for consideration of agriculture under the Green Climate Fund). Medium costs are estimated where our recommendation suggests a more involved intervention consisting of a number of measures, influencing a more complex set of stakeholders and requiring more background analysis (e.g., interventions targeting the donor community on rice or sustainable intensification; analysis of the

Chinese fertilizer management program). High costs are associated with interventions that require long-term research (e.g., on soil carbon) or broad outreach and campaigns (e.g., on shifting diets in the U.S. or China, or changing management practices in the diary sector in India).

Uncertainty and MRV Challenges

Relates to the availability of data and methodologies that allow the assessment of the mitigation potential and achievements of the proposed interventions. Uncertainty refers to the level of certainty with which the GHG reduction or removal can be established.

ANNEX 2.
BACKGROUND ON BIOFUELS AND SUBSIDIES

Note: The expansion of biofuels can lead to land use change and is an important driver of deforestation. Land use emissions are addressed as part of REDD+ strategies and falls outside of the scope of this report. The section below gives some background information, but does not claim to be complete or definitive. For more detailed information we refer to CLUA's Tropical Forest Carbon Strategy and the Bioenergy Strategy of the David and Lucile Packard Foundation for the years 2014–2016.

Bioenergy background

More than a decade ago, bioenergy emerged as what seemed like a possible cure for high dependence on emissions-intensive fossil energy, while promising new markets for agricultural crops and an avenue for rural development. Bioenergy was historically assumed to be carbon neutral based on the notion that any carbon released by the fuel would be taken up by the re-growth of the plant that was consumed for fuel (i.e., these feedstocks are usually considered part of the short-term carbon cycle), or would have released their stocks of CO_2 over time anyway. Some types of bioenergy are carbon neutral and thus provide net GHG benefits when used in place of fossil fuels. However, bioenergy can also result in net negative GHG emissions for several reasons: 1) the feedstock might not otherwise have been harvested and may have otherwise continued to sequester carbon, or might have otherwise taken many years to release its carbon stores; 2) the full life-cycle emissions associated with transportation and processing can vary greatly and can be significant in some cases; and 3) most importantly, the use of agricultural crops for biofuels has accelerated the expansion of agriculture and created competition for land, increased pressure on forests, and added to rising food prices. Further, biofuel demand can indirectly cause land use change (ILUC) by shifting and intensifying the production of commodities and associated GHG emissions elsewhere. These indirect effects can be difficult to track as they are triggered by complex factors such as global commodity prices. These effects can limit the mitigation effectiveness of biofuels.

As of 2010, roughly 3 percent of the world's crops were used to make biofuels (using global average yield), and to provide about 2.5 percent of today's global transportation fuels.[1] Any effort to generate a meaningful percentage of fuel from food crops (corn, sugarcane, soybeans and palm oil) for bioenergy either reduces food production, leads to large-scale land use change, or both.

Biofuel subsidies

The environmental benefits of biofuel use remain one of the main reasons for the biofuel subsidy policies in the U.S. and the E.U.[2] Policy mandates in the E.U. and the U.S. combined with subsidies helped raise domestic and international markets for biofuels.[3] In combination with high fossil fuel prices, these policies drove a dramatic production increase for conventional and new feedstock and soon lead to substantial distortions in global markets for food, feed, fiber and fuel. While initially created to address national concerns of energy security[4] and to support agricultural constituencies,[5] biofuel policies have global implications as biofuel feedstock compete with other uses of commodities, land and resources. Biofuel became particularly controversial after the food price crisis in 2007/08, where biofuel markets may have indirectly contributed to price volatility in the agricultural sector. The mitigation effectiveness of biofuels was particularly compromised by direct and indirect conversion of forests into cropland.

It has become clear that the current (first) generation of feedstocks generally provides marginal benefits in the net reduction of GHG emissions and incurs significant costs in terms of water, land and inputs.[6] While national situations vary regarding subsidy and mandate policies for biofuel production, an overall observation on the effects of such policies has found that concurrent mandates and subsidies often cannibalize each other or have no effect.[7] Furthermore, research has shown that any potential benefits from biofuel policies can easily be offset by the inefficiencies in other policies, such as trade barriers (e.g., import tariffs, domestic production subsidies and sustainability standards).

Several adjustments have been made to improve the sustainability objectives of biofuel policies, including improved mitigation outcomes. The expanded U.S. Renewable Fuel Standard (RFS2) includes mandatory limits for lifecycle emissions for different fuel categories.[8] Following its mandate from the Energy Independence and Security Act of 2007, the U.S. Environmental Protection Agency (EPA) issued a rule[9] including default values of GHG reduction potential, taking into account indirect land use change. A more recent assessment by Mosnier et al. (2012) indicates that the effects have been underestimated, for instance, by neglecting impacts on fertilizer use,[10] suggesting that corn ethanol especially provides scant mitigation benefits and leads to significant emissions outside of the U.S. In November 2013, the EPA proposed cuts to the biofuel mandate, specifically on the blending of corn ethanol, which has spurred controversial debates and is likely to be litigated by industry.[11]

Ethanol usage and production

While the U.S. is by far the world's largest ethanol user, ethanol is also supported by other countries, namely Brazil, Argentina, and the Ukraine. However, U.S. corn ethanol production remains double that of Brazil's sugar cane ethanol, the next highest producer country. Brazil relies heavily on biofuels in its transport sector, thanks to 25 years of policies encouraging ethanol production. As in the United States, farmers have adjusted to higher corn prices by adjusting crop rotations, converting pasture to cropland, reducing fallow periods—as well as putting new land into production. Broadly speaking, U.S. ethanol demand has buoyed corn prices worldwide, contributing to a long-term price rise over the last five years—although recently prices have retreated somewhat from those record highs. Brazil is also actively engaged in the promotion of ethanol, through advantageous trade and investment arrangements, as part of its 'soft-power' economic diplomacy with the rest of the world. With active diplomatic support and financing from the Brazilian government, Brazilian companies have become major investors in ethanol production in Africa and Central America. Most of the ethanol produced in these regions is destined for developed-world markets, and Brazil's overseas bet on ethanol is already generating 'food v. fuel' conflicts.[12]

Similar to the U.S., the E.U.'s framework policy for biofuels, the Renewable Energy Directive of 2009 established requirements for minimum GHG performance. In 2011, the E.U. Commission also adopted binding sustainability criteria that requires reporting of biofuel origin, minimum GHG performance based on life-cycle analysis or default values and exclude specific feedstock sources, such as those involving deforestation or conversion of land of "high biodiversity value". Accredited certification schemes may be used to prove compliance with criteria, including initiatives such as for instance the Roundtable for Sustainable Biomaterials or the Roundtable for Sustainable Palm Oil. Palm oil expansion, especially onto peatlands in Malaysia and Indonesia, constitutes one of the gravest global threats to successful reduction of GHG emissions from land-based sources. Safeguards are mainly addressed at concerns related to direct lifecycle emissions (and land use change) while the issue of ILUC has been more controversial.[13] In October 2012, the Commission proposed additional amendments to the Renewable Energy Directive: 1) Capping first-generation biofuels for transport at 5 percent; 2) factoring in ILUC into GHG emission calculations; 3) tightening the sustainability criteria by moving up the enforced 60 percent reduction of GHG emissions for petroleum fuel for new facilities to July 2014 rather than 2018; 4) and applying a multiplying factor to the quantities in national accounting to accelerate a transition to "advanced" biofuel types. This proposal was voted on in October 2013, and failed to receive the required two-thirds qualified majority vote for approval.[14] A new ballot for election will likely be submitted around May 2014.

Bioenergy from non-food crops

In contrast to first-generation biofuels, which are generally considered problematic, second-generation biofuels can offer a relatively clean alternative to fossil fuels used for transportation. Whereas first generation biofuels rely on food crops such as sugarcane and corn, second-generation biofuels are likely to rely on fast-growing perennials such as miscanthus, which generate fewer emissions from fertilizer, tillage, fermentation, and distilling. Furthermore, a number of agricultural-related feedstocks could be used as sustainable sources of bioenergy. This biomass energy will be harnessed in a range of forms, including direct combustion for heat and power, gasification to produce syngas and biochar, anaerobic digestion, ethanol production, thermochemical conversion of biomass-derived syngas to transportation fuels, and biodiesel.[15] Many potential feedstocks for bioenergy do not compete with food crops and do not face the technical challenges of "second generation" biofuels. These feedstocks include manures (e.g., using methane digesters addressed in Section 3.6), crop residues, forest residues, and municipal green waste. Use of these feedstocks may not always result in positive net GHG emissions benefits, but they are less likely to cause changes in land use which is the largest environmental concern associated with biofuels from agricultural crops. Bioenergy feedstocks can, though have a number of important competing uses (e.g., for soil fertility or livestock feed), so any policies or investments that support their use development need to be studied carefully to avoid perverse outcomes. Furthermore, though there may be some viable, sustainable, net positive GHG emissions sources of bioenergy which are worth pursuing, the overall potential for bioenergy globally needs to be kept in perspective. According to a recent report, diverting all of the world's recent annual harvest of biomass (i.e., all of the world's agricultural crops) towards energy use would generate only around 20 percent of world energy in 2050.[16]

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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] US: The first quantitative mandate for biofuels was introduced by the Renewable Fuel Standard (RFS), a provision of the Energy Policy Act of 2005 and expanded in 2007 by the Energy Independence and Security Act (RFS2). The RFS sets timetables, targets and caps for different categories of biofuels, including renewable fuel (corn-derived ethanol and advanced biofuel), advanced biofuel (cellulosic biofuel and biomass-based diesel), cellulosic biofuel and biomass-based diesel. The categories are further delineated by requirements for lifecycle GHG reduction etc. EU: The first binding mandate was set by Energy and Climate Change Package of 2009.

[3] US: The first quantitative mandate for biofuels was introduced by the Renewable Fuel Standard (RFS), a provision of the Energy Policy Act of 2005 and expanded in 2007 by the Energy Independence and Security Act (RFS2). EU: The first binding mandate was set by Energy and Climate Change Package of 2009. (2) Renewable Fuel Standard Assessment – White Paper, Energy Policy. 2013

[4] The Committee on Energy and Commerce. (2013). *Renewable Fuel Standard Assessment White Paper, Energy Policy.* Washington, D.C.: The Committee on Energy and Commerce.

[5] Gerasimchuk, I., Bridle, R., Beaton, C., Charles, C. (2012). *State of Play on Biofuel Subsidies: Are policies ready to shift?* Winnipeg, Manitoba, Canada: The International Institute for Sustainable Development.

[6] Organisation for Economic Co-operation and Development (OECD). (2008). *Biofuels: An Economic Assessment.* Paris: Organisation for Economic Co-operation and Development.; Rajagopal, D. and D. Zilberman. (2007). *Review of Environmental, Economic and Policy Aspects of Biofuels.* (The World Bank Policy Research Working Paper No. 4341). Washington, D.C.

[7] Gorter, H., Just, D. (2010). The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy. *Applied Economic Perspectives and Policy, 32,* 4-32.

[8] E.g. Renewable Fuels, including corn ethanol: Minimum GHG reduction of 20 percent; Advanced Fuels, including sugarcane ethanol: Minimum GHG reduction of 50 percent.

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[9] U.S. Environmental Protection Agency. (2010). *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis.* Retrieved 2013-14, from http://www.epa.gov/otaq/renewablefuels/420r10006.pdf.

[10] Mosnier, A., Havlík, P., Valin, H., Baker, J.S., Murray, B., Feng, S., Obersteiner, M., McCarl, B., Rose, S. and Schneider, U. (2012). *The Net Global Effects of Alternative U.S. Biofuel Mandates: Fossil Fuel Displacement, Indirect Land Use Change, and the Role of Agricultural Productivity Growth.* Durham, North Carolina: Nicholas Institute for Environmental Policy Solutions.

[11] Other reasons include reduced gasoline demand and limitations in the technical feasibility of blended fuels for vehicles.

[12] See for example Friends of the Earth International. (2010). EU-Brazil Biofuels Deal: Land-grabbing charter. Retrieved 2013-14, from http://www.foei.org/en/media/archive/2010/eu-brazil-biofuels-deal-land-grabbing-charter.

[13] Nelson, A. (2013). Biofuels industry sent 'three mails an hour' in ILUC lobby offensive. *Euractiv.* Retrieved 2013-14, from http://www.euractiv.com/energy/biofuels-industry-sent-mails-hou-news-519531.

[14] Nelson, A. (2013). Lawmakers vote to block EU biofuels bill. *Euractiv.* Retrieved 2013-14, from http://www.euractiv.com/energy/european-parliament-votes-block-news-531161.

[15] Eisentraut , A. (2010). Sustainable production of second-generation biofuels. *International Energy Agency.*

[16] Searchinger, T. et al (2013). See fn #1

ANNEX 3.
METHODOLOGIES USED TO ESTIMATE TECHNICAL MITIGATION POTENTIAL

This appendix explains how mitigation potentials were calculated for this report.

Methodological overview

This analysis estimates technical greenhouse gas mitigation potential for agriculture in 2030, calculated by country and emitting sector. Technical mitigation potential is equal to the emissions reductions possible with current technologies, ignoring economic and political constraints. Because agricultural emissions is a relatively data-poor field, 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.

This analysis provides a snapshot of potential avoided emissions in the year 2030, compared to a hypothetical baseline in which no additional mitigation from production agriculture is attempted, beyond what is expected given current adoption and intensification trends. It focuses on interventions directly related to production agriculture, such as reductions in emissions from livestock, rice, and other crops, as well as carbon sequestration in agricultural systems and reductions in demand. It prioritizes interventions which are unlikely to be realized through complementary mitigation efforts in the industrial, energy, or transportation sectors.

Mitigation potential is estimated assuming that the best currently-available technologies or practices could be employed widely. Where multiple technologies or practices are possible, the most effective interventions or suite of interventions is used to estimate a mitigation potential. Estimates are based on scholarly literature, reputable datasets, and expert interviews.

In the case of enteric fermentation, manure, rice, and fertilizer emissions, mitigation potential was calculated as a percentage reduction from 2030 emissions. Our projection shows that agricultural emissions will scale from 4.67 Mt CO_2e in 2010 to 5.19 Mt CO_2e in 2030. These 2030 emissions were estimated by scaling estimates of 2010 emissions from FAOSTAT by predicted emissions growth factors, specific to sector and country. These growth factors were derived from the agricultural emissions projections provided by EPA 2012. The growth factors, shown in the table below, were generated by the IFPRI impact model, except for rice harvesting which is based on FAPRI's "U.S. and World Agricultural Outlook". For further discussion of the various global agricultural emissions inventories and why this report uses FAOSTAT for its baseline emissions analysis, see the supplementary information provided at www.agriculturalmitigation.org.

Table 1. Emissions growth factors used to estimate 2030 baseline

Projected change in emissions, 2010–2030 (based on EPA 2012).

	Globe	China	India	Brazil	USA	E.U.
Total agric. emissions	20%	15%	14%	7%	23%	3%
Ag. soils	26%	23%	24%	9%	38%	7%
Enteric	20%	18%	14%	4%	9%	-2%
Manure management	11%	12%	17%	16%	0%	-3%
Rice	-2%	-14%	8%	-3%	-3%	1%

	Indonesia	Pakistan	Argentina	Australia	Mexico	Vietnam	Horn of Africa
Total agric. emissions	26%	43%	19%	15%	23%	23%	25%
Ag. soils	42%	32%	21%	20%	32%	34%	19%
Enteric	49%	53%	17%	13%	22%	41%	26%
Manure management	34%	29%	18%	8%	7%	25%	25%
Rice	3%	7%	22%	562%	1%	10%	-14%

In the case of carbon sequestration on grazing lands and croplands, this study relies on estimates provided in existing literature as well as an analysis conducted for this study to assess the mitigation potential of biochar from a range of feedstocks. Estimates for the mitigation potential for demand-side measures also rely on existing literature.

The methodology for each sector is described further, below.

All mitigation data used in this report are rounded to the nearest 5 Mt, even if the data point is drawn from published literature in which a higher level of precision is provided.

Boundaries of this analysis

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

- Because this report does not provide ranges or error bars in most cases, the data provides a false sense of precision. 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 about the economic costs and benefits of interventions across a range of geographies and production systems. 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, as well as in variation in what practices have already been implemented. Only a fraction of the technical mitigation potential shown in this report will be achievable given economic and political 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 complement each other and avoid potential double counting of mitigation opportunities. Although this report adds the mitigation potential from supply-side and demand-side interventions, these opportunities will certainly impact one another. Specifically, if demand for agricultural products decreases significantly, then the potential to reduce emissions from production will be smaller as a consequence.
- 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:

- Avoided deforestation
- Biofuels
- On-farm machinery and irrigation
- Restoration of abandoned lands
- Supply chain interventions, with the exception of fertilizer production in China

Further information

Further information on individual mitigation practices can be found in the supplementary information provided at www.agriculturalmitigation.org.

2.2 Enteric fermentation

This report estimates a mitigation potential of 940 Mt CO_2e per year by 2030 from reduced emissions from enteric fermentation from ruminants. This estimate corresponds to a roughly 40 percent reduction in emissions compared with baseline emissions projections. Technically, the largest opportunities are in India (135 Mt CO_2e per year) and Brazil (105 Mt CO_2e per year), followed by China (70 Mt CO_2e per year), the Horn of Africa (65 Mt CO_2e per year), the E.U. (60 Mt CO_2e per year), and the U.S. (50 Mt CO_2e per year).

The Horn of Africa includes the following countries:
Djibouti, Kenya, Somalia, Sudan (former)/ Sudan/ South Sudan, Uganda, Ethiopia

Methodology

- Hristov et al. (2013) provides percentage reduction in CO_2e from a range of specific practices such as, improved forage, feeding of concentrates, feeding of lipids, feeding of nitrates, vaccinations, and culling practices. Other literature and expert interviews were also considered.
- We assumed that the maximum potential percentage reduction was equal to the highest estimate for any of the practices (~40 percent reduction) and did not add the practices together. The only mitigation practices for enteric fermentation that can achieve 40 percent emissions reduction is nitrates (a feed supplement). However, a combination of other practices may also achieve this level of mitigation.
- We then multiplied the emissions from each ruminant livestock category (FAO 2010) by 40 percent to determine emissions reduction potential.

Primary data source

- Hristov, A.N., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A., Yang, W., Tricarico, J., Kebreab, E., Waghorn, G., Dijkstra, J. & Oosting, S. (2013). *Mitigation of greenhouse gas emissions in livestock production—A review of technical options for non-CO_2 emissions.* Gerber P., Henderson B., Makkar H. Rome, Italy: Food and Agriculture Organization of the United Nations.

2.3 Management of stored manure

This report estimates a mitigation potential of 260 Mt CO_2e per year by 2030 from reduced emissions from both methane and nitrous oxide emissions from stored manure. This estimate corresponds to a roughly 65 percent reduction in emissions compared with baseline emissions projections. Technically, the largest opportunities are in those countries which primarily use industrialized production for dairy, pigs and poultry: China (45 Mt CO_2e per year), the E.U. (45 Mt CO_2e per year), and the U.S. (40 Mt CO_2e per year). These animals spend most of their lives in confinement when raised in industrial systems.

Methodology

- Hristov et al. (2013) provides the percentage reduction in CO_2e from a range of specific practices such as methane digestion, composting, better timing of manure application on croplands, cooling of manure, reduced storage time, and improved animal diets. Other literature and expert interviews were also considered.
- We assumed that the maximum potential percentage reduction was equal to the highest estimate for any of the individual practices (70 percent reduction potential) and did not add the practices together. The only mitigation practices for stored manure that can achieve 70 percent emissions reduction is methane digestion. However, a combination of other practices may also achieve this level of mitigation.
- We assumed that this highpoint (70 percent reduction) could be applied to all stored manure.
- We then multiplied the emissions from each ruminant livestock category (FAO 2010) by 70 percent to determine emissions reduction potential.

Primary data source

- Hristov, (2013).

2.4 Carbon sequestration in grazing land

This report provides two estimates of mitigation potential from soil carbon sequestration in grazing lands: 170 Mt CO_2e per year and 395 Mt CO_2e per year. Since carbon sequestration in agricultural lands is not an emissions reduction, these mitigation estimates do not reflect a percentage of 2030 emissions.

The carbon sequestration potential of grazing lands is highly uncertain. 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. Thus, to be accurate, assessments of carbon sequestration potential in grazing lands should take into account what is actually happening on the ground. However data at this level of detail is not available across the globe, or even across large regions. Therefore, most global assessments of carbon sequestration potential in grazing lands use very simple methodologies whereby they apply sequestration rates found at a range of plot experiments and apply those rates across the globe, without a sophisticated understanding of the ground-level land use. Further, most grazing land sequestration studies to not attempt to model multiple practices as once.

Methodology

The first estimate draws from a 2002 publication by Rich Conant and Keith Paustian, estimating the soil carbon sequestration potential associated with rehabilitating all of the overgrazed grasslands in the world. We have included it in this analysis because it provides a conservative and globally consistent estimate. It is conservative because it only accounts for degraded lands. Grazing lands that are not degraded can also store more carbon through changes in practices, but that potential is not covered by this paper. For example, this paper only includes 14 out of 354 Mha (~4 percent) of grazing land in North America.

The second estimate draws from a range of papers that assess the soil carbon sequestration potential in grazing lands from different countries and regions, including regional level assessments from Conant and Paustian, 2002. The limitation of this estimate is that each of these papers employs a different approach and methodology and there also may be some geographic overlap between China and Eurasia. The sum, thus, represents a cobbling together of related, but inconsistent analysis. Nevertheless, we believe this aggregation provides a useful, and more realistic, estimate of soil carbon sequestration potential in the world's grazing lands. That said, this estimate may still be conservative since several of the analyses included also only assess the potential to restore degraded pastures, rather than exploring increased carbon storage on non-degraded pastures from a range of other practices.

In the table below, Thornton and Herrero, 2010, specify 2030 as the date by which this level of annual mitigation is possible. Wang et al. 2013 specify 2020 and Smith et al., 2007 specifies 2030. In all other cases, no specific year is provided.

Table 2: Grazing land soil carbon sequestration potential

Source	**Country/Region**	**Sequestration potential (Mt CO_2e per year)**	**Intervention**
Conant and Paustian, 2002	Global grazing lands	168	Decreasing grazing intensity on over grazed lands.
Conant and Pasutian source used for grazing lands soil carbon sequestration potential, low estimate.			
Wang et al. 2013	China	60	Grazing land restoration, grazing ban on 35% of China's grazing lands.
Thornton and Herrero, 2010	Central and South America	53.6	Restoration of degraded pastures.
Thornton and Herrero, 2010	Sub-Saharan Africa	96.7	Restoration of degraded pastures.
Conant and Paustian, 2002	Australia/Pacific	16	Decreasing grazing intensity on over grazed lands.
Conant and Paustian, 2002	Eurasia	16	Decreasing grazing intensity on over grazed lands.
Lal et al., 2003	U.S.	47.7 to 257 (average = 152)	Improved management practices on grazing lands.
Wang et al., Thornton and Herrero, Conant and Pasutian, and Lal et al. sources summed to provide grazing lands soil carbon sequestration potential, high estimate.			
R. Lal, 2004	Global range and grasslands	36.7 to 1,100 (average = 568)	A range of practices in semi-arid and sub-humid regions.
Smith et al., 2007	Grazing land management	~1,400	Improved management practices on grazing lands.
R. Lal, and Smith et al. sources provided for comparison.			

Primary data sources

- Conant and Paustian. 2002. "Potential soil carbon sequestration in overgrazed grassland ecosystems." Global Biochemical Cycles. vol. 16, no. 4.
- Wang, W., D. Moran, F. Koslowski, D. Nayak, E. Saetnan, P. Smith, A. Clare, E. Lin, L. Guo, J. Newbold, G. Pan, K. Cheng, X. Yan, L. Cardenas. (2013). *Economic potential of greenhouse gas mitigation measures in Chinese agriculture*. (Policy Brief No. 8) UK-China Sustainable Agriculture Innovation Network.
- Thornton and Herrero. (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *PNAS*, *107,* 19667-19672.
- Lal, R., R. F. Follet, J. M. Kimble. (2003). Achieving soil carbon sequestration in the United States: A challenge to policy makers. *Soil Science, 168*, *12,* 827–845.
- R. Lal. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304,* 1623.
- 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. *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.

2.5 Agroforestry

This report estimates a mitigation potential of 105 Mt CO_2e per year by 2030 from carbon sequestration associated with the adoption of agroforestry practices in mixed crop-livestock systems in humid and tropical highland areas of the developing world, specifically Central and South America, Sub-Saharan Africa, South Asia, and Southeast Asia. Adoption rates of roughly 1 percent and a per hectare sequestration potential of 38 t C (139 t CO_2) are assumed. However, this estimate is highly uncertain, particularly as agroforestry systems vary widely in type and are often cut down at varying intervals.

Primary data source

- Thornton and Herrero, (2010).

2.6 Rice management

This report estimates a mitigation potential of 120 Mt CO_2e per year by 2030 from reduced methane emissions from rice production. This estimate corresponds to a roughly 25 percent reduction in emissions compared with baseline emissions projections. Since the vast majority of rice is produced in Southeast Asia, the mitigation potential is concentrated in that geography, although spread across the many countries in that region. Countries with relatively high mitigation potential for improved rice management through methane reductions include China (25 Mt CO_2e per year), the Philippines (20 Mt CO_2e per year), India (15 Mt CO_2e per year), Indonesia (12 Mt CO_2e per year), and Vietnam (10 Mt CO_2e per year).

Rice cultivation produces methane emissions when cultivation occurs in flooded fields, as well as nitrous oxide emissions from applied nutrients. For the purposes of this analysis, all nutrient emissions for all crops, including rice, are treated in Section 2.7, below. The rice mitigation opportunity described here includes only methane emissions reductions; the total mitigation potential for rice is larger if nutrient reduction potential is also considered.

Note that because this report calculated mitigation potential based on assumed emissions reduction potential off of a projected baseline, the trajectory of the baseline has a significant influence on the size of the mitigation opportunity. The emissions growth factors used this report project negative growth for rice (see Table 1). If rice production and emissions instead grow over the coming decades, then the mitigation potential in 2030 would be larger than what is reported here.

Methodology

- To estimate mitigation potential from rice methane, we focused on straw management (e.g., off season application of rice straw) and water management (e.g., one mid-season drainage, multiple mid-season drainages, shallow flooding), the two practice categories that are most often addressed in the literature. We drew primarily from the estimates for emissions reduction provided by Yan et al. 2009.
- Based on Yan et al., we used 16 percent emissions reduction potential for both straw management and water management.
- We used FAOSTAT (scaled by EPA 2012 growth factors) to determine the applicable 2030 rice emissions for each country. Since water management and rice straw application require some type of drainage, we assumed they are only applicable on irrigated cropland. We used a data set shared by the International Rice Research Institute which provided the percentage of irrigated cropland in each rice-producing country in Asia. For the U.S., we used the applicable hectares from Eagle et al.

2001 (T-AGG, 2011). We multiplied the percent of irrigated hectares by the total rice emissions per country to estimate the applicable emissions.

- We then multiplied Yan's percentage emissions reduction estimates by the applicable rice emissions. We added the mitigation potential for rice straw and water management since they can be practiced in conjunction.

Primary data sources

- Yan, X., H. Akiyama, K. Yagi, and H. Akimoto. (2009). Global estimations of the inventory and mitigation potential of methane emissions from rice cultivation conducted using the 2006 Intergovernmental Panel on Climate Change Guidelines. *Global Biogeochemical Cycles, 23,* GB2002. doi:10.1029/2008GB003299.
- A.J. Eagle, L. Henry, L. Olander, K. Haugen-Kozyra, N. Millar, G. P. Robertson. (2011). *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature, 2nd Edition*. Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University. http://nicholasinstitute.duke.edu/ecosystem/land/TAGGDLitRev.
- Unpublished spreadsheet shared via email by Andy Nelson (International Rice Research Institute) on August 19, 2013.

2.7 Nutrient management

This report estimates a mitigation potential of 325 Mt CO_2e per year by 2030 from reduced nitrous oxide emissions from all crops. This estimate corresponds to a roughly 30 percent reduction in emissions compared with baseline emissions projections. Technically, the largest opportunities are in China (150 Mt CO_2e per year) and India (70 Mt CO_2e per year). The mitigation potential in the U.S., E.U., and Brazil are relatively small at 20, 10, and 10 Mt CO_2e per year respectively.

This report calculates the emissions reductions associated with transitioning all of the world’s crops to 55 percent nutrient use efficiency (NUE). We did not change the NUE rate for those countries that already have an average NUE rate of 55 percent or higher. A key assumption is that there is a one to one relationship between nutrients applied and nitrous oxide emissions (i.e., that a 30 percent reduction in applied nutrients corresponds to a 30 percent reduction in nitrous oxide emissions). This treatment is a simplification; in fact, the relationship between nitrogen application and N_2O emissions is almost certainly non-linear. A recent meta-analysis found that yield-scaled N_2O emissions were smallest at application rates of approximately 180–190 kg N per hectare and increased sharply after that.[1] This finding implies that as long as the nutrients can be used by the crops, emissions will be low or stable, but once nutrient application rates are in excess of what the crops can take up, emissions will spike. A further implication is that regions that are under-applying nutrients (e.g., Sub-Saharan Africa) could greatly increase their use of fertilizers without a corresponding increase in emissions.

Methodology

- Our assessment for this segment of the analysis relied heavily on data provided by Paul West, Institute on the Environment, University of Minnesota. This data included total applied nitrogen (kg) by country for the year 2000 as well as the total excess nitrogen (kg) by country for the same year.
- The nitrogen input data were derived from a few sources. Applied chemical fertilizer was compiled from application rates defined by the International Fertilizer Association, as well as country- and state-level consumption rates provided in agricultural census records and fertilizer sales data. This compilation is described in Mueller et al. 2012. Atmospheric nitrogen input data were from

Dentener et al. 2007 that were estimated and used for the IPPC AR4. Manure was calculated based on livestock density and nitrogen content in manure. Nitrogen-fixation was estimating by scaling crop-specific fixation rates by yield. Excess nitrogen was calculated using a mass balance approach to determine the delta between applied nitrogen and nitrogen used by crops.

- Based on these two data sets, we back-calculated the total amount of nitrogen used by the crops as well as an implied NUE rate. The implied global NUE rate is 38 percent. The implied NUE rates for China, India, the U.S. and the E.U. are 27, 26, 46 and 52 percent respectively.
- We then calculated what the applied nitrogen rate would have been if 55 percent NUE had been realized, based on the same level of nitrogen used by the crops. We were then able to compare the amount of excess nitrogen based on current NUE with the amount of excess nitrogen we would see if global crops achieved 55 percent NUE. We determined a percentage of applied nitrogen reduction from this delta. We selected 55 percent as a target based on Ladha et al. 2005, which found 55 percent to be the global average NUE achieved from 93 experimental plots.
- Finally, we applied these reduction potentials on a global and country-level basis to our 2030 baseline crop-related nitrous oxide emissions.

Data sources

- Unpublished spreadsheet shared via email by Paul West, Institute on the Environment, University of Minnesota (January, 2014).
- Muller, N., J. Gerber, M. Johnston, D. Ray, N. Ramankutty, J. Foley. (2012). Closing yield gaps through nutrient and water management. *Nature, 490,* 254–257.
- Dentener, F., J. Drevet, J. F. Lamarque, I. Bey, B. Eickhout, A. M. Fiore, D. Hauglustaine, L. W. Horowitz, M. Krol, U. C. Kulshrestha, M. Lawrence, C. Galy-Lacaux, S. Rast, D. Shindell, D. Stevenson, T. Van Noije, C. Atherton, N. Bell, D. Bergman, T. Butler, J. Cofala, B. Collins, R. Doherty, K. Ellingsen, J. Galloway, M, Gauss, V. Montanaro, J. F. Muller, G. Pitari, J. Rodriguez, M. Sanderson, F. Solomon, S. Strahan, M. Schultz, K. Sudo, S. Szopa, O. Wild. (2006). Nitrogen and sulfur deposition on regional and global scales: A multimodal evaluation. *Global Biogeochemical Cycles, 20.*
- Ladha, J., H. Pathak, T. Krupnik, J. Six, C. van Kessel. (2005). Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in Agronomy*, 87.

2.8 Carbon sequestration in croplands

This report provides two estimates of mitigation potential from soil carbon sequestration in crops lands: 435 Mt CO_2e per year and 1,135 Mt CO_2e per year. Both of these estimates were calculated based on an analysis built upon Woolf et al. 2010. This analysis calculates the net greenhouse gas benefits of a one-time application of 50 t C per hectare of biochar produced in a “modern” facility, based on a model of regionally available carbon feedstocks (e.g., rice straw, forest residues, bioenergy crops on abandoned lands).While the stability of the carbon in biochar depends on the conditions under which it is produced as well as the feedstock, it is more stable than the carbon in non-charred biomass and therefore can sequester the carbon for longer. This analysis assumed biochar carbon resided in two “stability” pools, a labile pool (15 percent) with a half-life of 20 years, and a recalcitrant pool (85 percent) with a half-life of 300 years. The half-life of the feedstock biomass if left in the field was assumed to be 1 year for herbaceous biomass, and 3 years for woody biomass. This analysis provides a useful estimate of the technical carbon sequestration potential in agricultural soils, by country, based on carbon sources that do not have competing uses.

That said, there are several aspects of this analysis that are probably unrealistic from a social and economic perspective. For example, this analysis assumes that all of the biochar would be produced in “modern facilities”, even though most farmers today do not have access to such facilities. Further, the analysis assumes very high (albeit one-time) rates of biochar application which may not be economically viable or practicable for most farmers. Also, while this analysis attempts to include only feedstocks which do not have competing uses, it is very difficult to determine definitively whether or not a certain feedstock actually has a competing use or what the ramifications are of changing the usage. Finally, one of the most important feedstocks for this analysis is residues from rice production. 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.

Methodology

- The biochar analysis was performed as a stand-alone analysis by James Amonette, Pacific Northwest National Laboratory. It estimates the regional mitigation potential of cropland-applied biochar created from a range of feedstocks, including crop residues, bioenergy crops grown on abandoned lands, and forest residues. Assumptions about available feedstocks are intended to be conservative and employ only “waste biomass."
- The biochar is assumed to be produced in a modern production facility. Note that the mitigation potential presented includes a technology adoption function that assumes a 5-year lead time, and slow ramping of production over the next 40 years as well as a full accounting of the GHG impacts of biochar production (e.g., the energy used in the process, the avoided GHGs from feedstock decomposition, soil carbon sequestration, fossil-fuel displacement).
- The analysis also incorporates biochar’s agronomic yield benefits, which are assumed to cause GHG benefits through its land sparing effects.
- It assumed that 50 tonnes of biochar is applied only once to each hectare, with lasting effects. New hectares receive a biochar application in each year of the simulation, such that all arable land has received an application of biochar after ~70 years.
- Additional details about the methodology are available upon request.

Table 3. Global biochar feedstock assumptions and *cumulative*, net avoided GHG by 2030

Feedstock class	Pg C per year feedstock	Description of assumptions
Rice	0.31	Rice husks and 70% of paddy rice straw not used for animal feed
Manures	0.17	12.5% of cattle manure plus 50% of pig and poultry manure
Sugar cane	0.13	Waste bagasse plus 25% of field trash
Green/ wood waste	0.18	75% of low-end estimate of yard-trimmings production and wood-milling residues
Other cereals	0.094	8% of total straw and stover (assumes 25% extraction rate of crop residues minus quantity used as animal feed)
Biomass crops	0.24	50% of potential production of abandoned, degraded cropland that is not in other use
Forestry residues	0.059	44% of difference between reported fellings and extraction
Total, not including enhanced yield	1.18	

- The term "biochar" represents a large group of pyrolysis products having a range of properties, and thus is far from being a single commodity or a panacea. As a result, care must be taken in matching biochars from a particular feedstock and pyrolysis process with a soil and cropping system. While, on average, biochar amendments seem to provide mitigation and economic benefits, in some situations, biochar does not represent the best use of biomass. These trade-offs are described in Woolf et al. 2010. In addition to the potential agronomic benefits, which vary with different groupings of biochar, soil, and cropping system, the carbon-intensity of the energy being offset by biochar production strongly influences its mitigation potential relative to 100 percent bioenergy production from the same feedstock. To the extent permitted by available data, these factors were considered in the biochar analysis.

This report calculates two estimates of the mitigation potential from biochar, both based on the analysis described above.

1. **The first estimate** is the more conservative of the two, totaling 435 Mt CO_2e per year. This estimate includes only crop residue and forest residue feedstocks, omitting biomass crops and the increased soil carbon sequestration associated with enhanced yields from the agronomic benefits of biochar. Additionally, it omits all of the avoided emissions elements of the full life cycle analysis, most notably avoided methane emissions associated with the removal of rice straw from the field and fossil fuel offsets from the syngas created during the pyrolysis process. Because this report does not included bioenergy, even on degraded lands, does not include the fossil fuel offsets associated with methane digestion of stored manure, and already accounts for emissions savings associated with removal of rice straw, this lower-bound biochar estimate is consistent with the rest of the analysis.
2. **The second estimate** includes biomass crops grown on degraded lands, the benefits of enhanced yields, as well as all avoided emissions (e.g., fossil fuel offsets and avoided methane emissions from rice straw left on the field). Although this estimate is less aligned with the rest of the analysis presented in this report, we felt it was important to provide the reader with a clearer sense of the total technical mitigation potential from biochar.
3. **Neither of the estimates** include biochar produced from manure or agroforestry residues because this report treats mitigation from both of these sources separately.

Additional soil carbon sequestration potential

We recognize that biochar is not the only mitigation practice associated with soil carbon sequestration on croplands, and that there is an enormous body of scientific literature dedicated to understanding the mitigation potential from these other practices (e.g., reduced- or no- tillage, improved management of crop residues, cover crops, and perennials). Unfortunately, we were unable to find recent analyses that provide global estimates of carbon sequestration potential on croplands. While several regional analyses exist, we did not include an aggregate sum from these studies because many of them rely on improved crop residue management which overlaps (double counts) with the biochar analysis. The findings from these studies are included in the table below for comparative purposes. In most cases, no year is provided by which these sequestration potentials might be achieved. Further, though estimates for sequestration potential using no-tillage systems are provided, it is important to note that there is currently significant scientific debate about the sequestration potential of no-tillage.[2]

Table 4. Cropland soil carbon sequestration potential

Source	Country/Region	Sequestration potential (Mt CO_2e per year)	Agricultural practice
Eagle et al., 2011	United States	29 to 173 (average 101)	Reduced and no-tillage
Grace et al., 2011	Indo-Gangetic Plain	186, over 20 years	No-tillage
Cerri et al., 2010	Brazil	11.5 to 46.2 (average 28.9)	No-tillage
Freibauer et al., 2004	Europe	103	No-tillage
Eagle et al., 2011	United States	36 to 150 (average 93)	Crop residue management
Lu et al., 2009	China	126	Crop residue management
Freibauer et al., 2004	Europe	95	Crop residue management

Primary data sources

- Biochar calculations were performed using BGRAM 1.2, which has been modified by JE Amonette from BGRAM 1.1 (Woolf D, JE Amonette, FA Street-Perrott, J Lehmann, and S Joseph. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications 1*, 56.) to process national and regional data.
- A.J. Eagle, L. Henry, L. Olander, K. Haugen-Kozyra, N. Millar, G. P. Robertson. (2011). *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature, 2nd Edition*. Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University. http://nicholasinstitute.duke.edu/ecosystem/land/TAGGDLitRev.
- Grace, P., J. Antle, P.K. Aggarwal, S. Ogle, K. Paustian, B. Basso. (2011_. Soil carbon sequestration and associated economic costs for farming systems of the Indo-Gangetic Plain: A meta-analysis. *Agriculture, Ecosystems and Environment. 146,*137–146.
- Cerri, C., M. Bernoux, S. Maia, C. Cerri, C. Costa, B. Feigl, L Frazao, F. Mello, M. Galdos, C. Moreira, J. Carvalho. (2010). Greenhouse has mitigation options in Brazil for land-use change, livestock and agriculture. *Scientia Agricola, 67.1,* 102–116.
- Freibauer, A., M. Rounsevell, P. Smith, J. Verhagen. (2004). Carbon sequestration in the agricultural soils of Europe. *Geoderma, 122.1.* 1–23.

- Lu, F., X. Wang, B. Han, Z. Ouyang, Z. Duan, H. Zheng, H. Miao. (2009). Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China's cropland. *Global Change Biology, 15,* 281–305.

2.9 Supply chain and demand-side measures

Fertilizer production in China (160 Mt CO_2e per year)

- Emissions from Chinese fertilizer production could be reduced 160 Mt CO_2e per year below a business-as-usual scenario for (BAU) by 2030 by improving manufacturing technologies. This assumes fairly aggressive reductions in emissions from coal energy generation, which may be outside the scope of agricultural mitigation efforts.

Primary data source

- Source: Zhang, W., Z. Dou, P. He, X. Ju, D. Powlson, D. Chadwick, D. Norse, Y. Lu, Y. Zhang, L. Wu, X. Chen, K. Cassman, F. Zhang. (2013). New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *PNAS, 110.*

Reduce food waste (760 Mt CO_2e per year)

- The conclusions in this report pull from the limited existing literature on the mitigation potential from reducing food waste. This number is highly uncertain.
- Smith et al., 2013 estimate a range of 760 to 1,500 Mt CO_2e per year by 2050 from a reduction in food supply chain losses and wastes. We halved those numbers to determine mitigation potentials in 2030, assuming a linear trajectory. Thus we present 380 to 760 as a low and medium range for mitigation potential from food losses and wastes in 2030.
- For a high end, we took a different approach. A recent paper published by FAO estimates 3.3 Gt CO_2e as the annual emissions footprint of food losses and wastage across the supply chain. 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”. Using 64 percent as the ratio for avoidable losses and wastage across the entire globe, applied to the FAO estimate of 3.3 Gt, yields a mitigation potential of 2.1 Gt per year.
- These estimates are clearly rough. Further, the actual effects of reducing food waste on food production are highly uncertain. For example, a decrease in demand might lower prices, causing producers to expand production to try to achieve profitability, or producers could transition to biofuels of alternative uses of the land which may or may not reduce emissions.

Primary data sources

- Smith, P., H. Haberl, A. Popp, K Erb, C. Lauk, R. Harper, F. Tubiello, A. Pinto, M. Jafari, S. Sohi, O. Masera, H. Bottcher, G. Berndes, M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. Elsiddig, C. Mbow, N. Ravindranath, C. Rice, C. Abad, A. Romanovskaya, F. Sperling, M. Herrero, J. House, S. Rose. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals?” *Global Change Biology, 19*, 2285–2302.
- 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.
- Parfitt, J., M. Barthel, S. Macnaughton. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*, 3065–3081.

Change in diets (2.15 Gt CO_2e per year)

- This report provides an estimate of the reduction in agricultural and land use change emissions if the world's population ate less animal products. The low estimate (0 Gt CO_2e per year) assumes no change in production as a result of dietary shifts, the midpoint (2.15 Gt CO_2e per year) assumes the global population adopts a "healthy diet," and the high estimate assumes that the global population eats no meat at all (3.2 Gt CO_2e per year).
- This report uses the midpoint estimate. The "healthy diet" scenario prescribes daily protein intake of 90 g per day, based on guidelines by Harvard Medical School. This diet leads to higher meat intake than in the reference case for some developing countries, but much less than typical daily American diet today. The 2030 mitigation potentials were assumed to be 50 percent of the 2050 potential estimated in Stehfest et al.
- 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 and it is unrealistic to assume that the global population might reduce its meat consumption so significantly in the aggregate. We have included this calculation primarily to demonstrate the outsized impact of dietary shifts over large populations.
- Primary data source: Stehfest, E., L. Bouwman, D. van Vuuren, M. den Elzen, B. Eickhout, P. Kabat. (2009). Climate benefits of changing diet. *Climatic Change, 95,* 83–102. DOI 10.1007/s10584-008-9534-6. These scenarios were generated using an integrated assessment model (IMAGE 2.4).

Additional supply chain opportunities not included in this analysis

- Assessing the mitigation potential in the agricultural supply chain was not squarely within the scope of this report in large part because mitigation along the supply chain may be best addressed in the context of efforts focusing on the energy, building, transportation, or industrial sectors. There are, however, additional mitigation opportunities worth mentioning. Note that neither of these opportunities are addressed in this report or the aggregated analysis.
- Cold chain (250 Mt CO_2e per year) It is estimated that 50 percent of the 500 Mt CO_2e per year in cold chain GHG emissions could be reduced through technologies such as more efficient retail displays, storage methods, and transportation, based on a study of cold emissions in the UK. This estimate is probably conservative it is based off of current emissions, yet cold chain emissions are likely to grow significantly by 2030, as the developing world adopts food supply chains that increasingly rely upon refrigeration.
- Primary data source: James, SJ, C James. (2010). The Food Cold-Chain and Climate Change. *Food Research International, 23.*
- Other supply chain interventions (300–400 Mt CO_2e per year) Published estimates and our calculations suggest that other supply chain interventions might yield reductions of 300–400 Mt CO_2e per year, through efficiencies in on farm-equipment, irrigation, processing, packaging, and transport, retail, catering, and food management, and waste.
- Primary data source:
- 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. *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.

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[1] Van Groenigen, J., Velthof, G., Oenema, O., Groenigen, K., Van Kessel, C. (2010). Towards an agronomic assessment of N_2O emissions: a case study for arable crops. *European Journal of Soil Science, 61,* 903-913.

[2] 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.