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The technical mitigation potential of demand-side measures in the agri-food sector:

A preliminary assessment of available measures

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Abbreviations and acronyms

AFOLU	Agriculture, forestry and other land use
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CDP	Carbon Disclosure Project
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
LCTPi	Low Carbon Technology Partnership initiative
NDC	Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PHHS	Post-Harvest Handling and Storage
PPP	Public-private partnerships
PSNP	Productive Safety Net Programme
RCT	Randomized Controlled Trials
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WRAP	Waste and Resources Action Programme
ZECC	Zero Energy Cooling Chambers

Summary

A number of studies have suggested that addressing greenhouse gas (GHG) emissions from agricultural production, or 'supply-side emissions', will be insufficient to reduce agri-food sector GHG emissions to limit the increase of global temperatures to well below 2°C. Recent studies have also suggested that 'demand-side measures' related to food consumption, food value chains, and food loss and waste, will be necessary to reduce emissions and may have a larger technical mitigation potential than supply-side measures.

This report assesses the availability of demand-side policies and measures, and looks at evidence of these measures' impacts on behavior that directly results in emissions from the agri-food sector. Often discussed demand-side measures include 'soft' measures (e.g. health promotion initiatives, product labeling) and 'hard' measures (e.g. consumption taxes or subsidies). We review here the effectiveness of these measures for dietary change and reductions in food loss and waste, with a focus on developing countries, where agri-food emissions are projected to grow most rapidly and where the gaps in knowledge are largest.

Key policy implications from the analysis are:

- **Set realistic expectations for mitigation from demand-side measures that can be implemented, as the feasible mitigation potential of demand-side measures is likely much lower than current estimates of the technical mitigation potential:** Evidence on the feasibility and effectiveness of demand-side measures in developing countries is very limited, and evidence from developed countries suggests that the feasible mitigation potential of demand-side measures is likely to be significantly lower than current estimates of the technical mitigation potential of demand-side measures.
- **Pursue shifting consumption away from livestock products as a major opportunity for mitigation:** Ruminant livestock products will likely dominate the global environmental impacts of agricultural production, given the relative inefficiency of livestock conversion of feed, forage and other resources to produce nutrients for consumption, with particularly high water, carbon and nitrogen footprints compared to other food sources. Together with cereals, and vegetables, meat products account for more than 70% of the global carbon footprint of food loss and waste.
- **Make linkages with other policy domains such as health, nutrition and business efficiency to promote mitigation through dietary change and reductions in food loss and waste:** Measures to promote dietary change will be more likely to be successful where they relate to other significant societal concerns, such as those related to the health burden associated with the nutrition transition.
- **Focus on emissions hot spots and value chains with a higher degree of concentration among producers or retailers:** The transaction costs of addressing supply- or demand-side emissions are likely to be lower in value chains that are dominated by a small number of downstream companies (e.g. supermarkets or specialist retailers) or upstream actors (e.g. manufacturers of branded products, exporters, farmer commodity associations). Value chain analysis can be useful in understanding food loss and waste hotspots in more fragmented value chains and in supporting the commercialization of solutions to reduce food loss and waste.
- **Enable the private sector to invest in reducing emissions from food loss and waste:** To increase private sector investments for reduced food loss and waste, support (i) investments in physical infrastructure, through public-private platforms for cooperation, (ii) the development of commercially viable investment proposals, and (iii) raising awareness among financial institutions of which types of activity are ready for investment to scale up.

Policy mechanisms to support shifts in diets or reduced food loss and waste to reduce emissions vary in their strengths and weaknesses. Table 3 summarizes the strengths and limitations of different demand-side measures. Evidence suggests that packages of policy mechanisms and interventions are more likely to be effective than any one measure.

Table 3. Qualitative summary of evidence on the strengths and weaknesses of potential demand-side measures for mitigation of GHG emissions

Approach	Strengths	Limitations
Dietary change		
Subsidies to 'healthy' foods	Consistent evidence that subsidies increase consumption of targeted food types.	Effects on overall consumption (and thus GHG footprint) unclear; Possible 'rebound effects' unclear.
Taxes on 'unhealthy' foods	Modeled evidence potential to change consumption of high GHG footprint products; Some evidence of dietary change among specific subgroups for targeted foods.	Very little empirical evidence on meat taxes or on taxes in developing countries; Effects on overall diets, on low income groups and on the agri-food sector unclear, including possible 'rebound effects'; Political barriers likely to be high.
Public health promotion of 'healthy' foods	More successful when 'at risk' groups targeted; Likely to have public & policy makers' support.	Evidence suggests variable and small long-term changes in consumption.
Public health promotion to reduce disease risks	Some evidence of effective school-based initiatives, including in developing countries; Likely to have public & policy makers' support.	Evidence suggests positive but small health benefits when general population targeted; Specific evidence on dietary change due to interventions insufficient to estimate GHG benefits.
Restrictions on advertising	Likely to have strong public support.	Limited evidence of reductions in exposure to advertising or on actual consumption.
Product labeling		Other factors likely to dominate purchase decisions; Little evidence of carbon labeling impact on purchasing decisions; Limited demand from consumers or retailers.
Sustainability certification	Growth in internationally traded commodities.	No evidence relating to meat.
Food loss & waste		
Technology-based approaches	Numerous potential applications; Likely to have strong private sector involvement.	Empirical evidence of effective reductions in loss & waste; Initial investment costs can be high for smallholders; Commercialization of technical options often limited.
Value chain approaches	Numerous potential applications and measures; Likely synergies with profit-making incentives of value chain actors.	Quantitative data on effective reductions in loss & waste limited; May require complex collaboration among value chain actors as well as government, civil society, finance sector.
Policy approaches	Numerous potential measures; Can play key roles in mobilizing other agri-food chain actors; Likely potential to mobilize private sector investment.	May require complex collaboration among agri-food sector stakeholders, including various government ministries, civil society, private sector, finance sector.

The evidence underlying these findings is mixed in availability and quality. It is particularly poor in the developing world. Examining the evidence for each category of policy mechanism, we found the following:

Consumption taxes and subsidies: Evidence is mostly available for developed countries and much of it is limited to modeling or experimental studies. This evidence suggests that subsidies on ‘healthy’ foods are generally able to increase the consumption of targeted foods. Evidence on taxation is more mixed. Existing tax rates on some food products are often too small to have significant impacts. Overall, too little is understood about substitution effects that might reduce or counteract the intended policy objectives; about the distributional effects of taxes; and about the effects on the agri-food sector.

Health promotion and labeling initiatives: There is little direct evidence on the effects of health education measures on meat consumption, and little research has been conducted in developing countries where the majority of the future increase in livestock product consumption is projected to occur. Evidence from developed countries suggests that most initiatives have small and sometimes insignificant impacts on dietary intake and health outcomes (e.g. obesity, diabetes and cardiovascular disease). Evidence on the specific effects on dietary composition is generally missing for health interventions, owing to measurement difficulties. Studies on the effectiveness of product nutrition labeling generally confirm that other factors, such as price, quality, taste, convenience and habit, play a greater role in shaping consumers’ decisions than information provision.

Evidence on measures to reduce waste and losses: There is evidence that a range of technical, value chain and policy measures can effectively reduce food waste and losses in developing countries. However, various barriers to adoption exist.

As a result of these gaps in evidence, key areas for future research are:

1. Quantify demand-side GHG mitigation potential based on what is economically and socially feasible;
2. Identify the conditions enabling synergies in policy approaches with other sectors
3. Identify emissions hotspots in specific value chains and analyze how to best engage with related value-chain actors
4. Analyze conditions needed to encourage more private sector investment in reducing food loss and waste and related emissions.

1. Overview and current state of the debate

1.1 The critical role of livestock GHG emissions in agricultural GHG emissions

The Intergovernmental Panel on Climate Change´s (IPCC) Fifth Assessment Report (Smith et al. 2014) estimated that greenhouse gas (GHG) emissions from agriculture, forestry and other land use (AFOLU) activities amount to approximately 9–12 Gt CO_2eq per year, or approximately 24% of global GHG emissions. Within the AFOLU sector, agricultural production contributed 5.0–5.8 Gt CO_2eq per year between 2000–2010 (i.e. approximately 14.5% of global emissions), while land use and land use change contributed approximately 4.3–5.5 Gt CO_2eq per year during the same period. Since the year 2000, annual GHG emissions from agricultural production have been larger than carbon dioxide (CO_2) emissions from deforestation, and agricultural emissions have been growing at a rate of about 1% per year (Tubiello et al. 2014)[1]. These estimates do not consider either emissions embodied in agricultural inputs (e.g. feed, fertilizer and pesticide production) or post-harvest emissions in the transport, storage, processing, retail, consumption and disposal of agri-food products, which may amount to about 1.8–2.3 Gt CO_2eq per year (Vermeulen et al. 2012). Available evidence suggests, however, that agricultural production is the main source of GHG emissions in many agri-food supply chains.

[1] Note that these estimates do not include CO_2 emissions from agricultural soils or other emissions from agricultural operations accounted for in other sectors (Tubiello et al. 2014).

The majority of GHG emissions from agricultural activities are in the form of methane (CH_4, accounting for 47% of total anthropogenic CH_4 emissions) and nitrous oxide (N_2O, accounting for 58% of total anthropogenic N_2O emissions). The largest agricultural source of CH_4 is enteric fermentation from ruminant livestock (e.g. cattle, sheep, goats), and the main N_2O sources are livestock manure management and fertilizer application. Enteric fermentation, the largest single source of GHGs in the agricultural sector, contributes about 40% of the sector´s GHG emissions (Figure 1, Tubiello et al. 2014). GHG emissions from enteric fermentation have been increasing in developing countries, rising by 35% between 1990 and 2011, with the most rapid growth in Africa (2.7% per year) and Asia (2.0% per year) (Tubiello et al. 2014). Considering also that about one third of global cropland is used to produce livestock feed (Herrero et al. 2013) and that both feed production and livestock grazing have been identified as a drivers of land use change in some regions (Kissinger et al. 2012), the significant role of livestock production and the consumption of livestock products in contributing to GHG emissions in the AFOLU sector is thrown into the spotlight. Beyond GHG emissions and land use change, other environmental impacts of livestock production have also been well documented, including land degradation, biodiversity loss, pollution of water bodies and soils by livestock waste, and a significant water footprint (FAO 2006; Mekonnen and Hoekstra 2012).

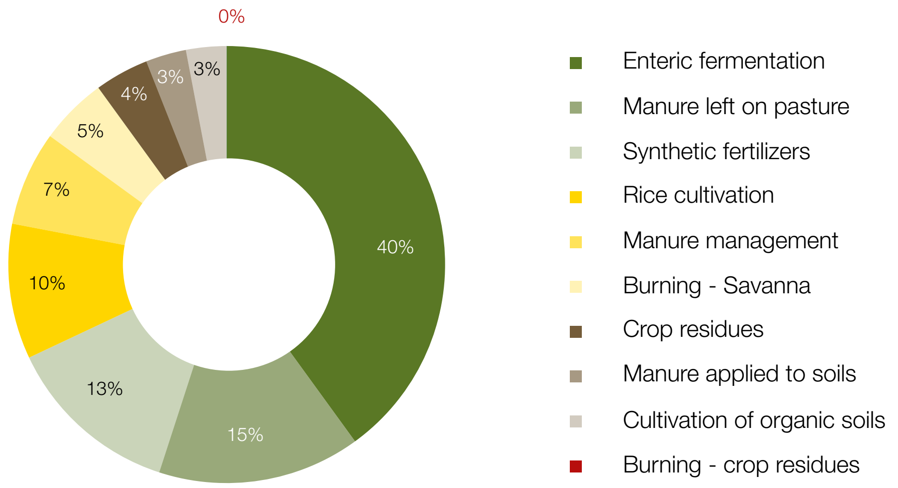


Figure 1.
Agricultural emissions by source, 2000-2011.
Source:
Adapted from Tubiello et al. 2014.

Agricultural GHG mitigation options are generally well known and have a technical mitigation potential of 7.18 – 10.6 $MtCO_2e$ at carbon prices up to USD100, about one third of which is available at a carbon price of less than USD20 (Smith et al. 2014). In the livestock sector, mitigation options are also known, and it has been suggested that about 30% of livestock GHG emissions could be avoided if all producers were able to achieve the emission intensities of the top 10% of producers (Gerber et al. 2013). However, a number of studies have identified a range of barriers to adoption (Lipper et al. 2010; Wollenberg et al. 2011; Smith et al. 2014). Cost barriers faced by farmers may include investment barriers, variable and maintenance costs, opportunity costs, transaction costs and risk costs. Other barriers to adoption may include collective action failures, tenure insecurity, and imperfect markets for credit and agricultural products. These barriers suggest a need for a range of measures in order to realize even part of the technical mitigation potential of supply-side agricultural measures. In addition, trade-offs between more efficient livestock production and other social concerns and policy objectives (e.g. environmental and animal welfare impacts of intensification) may limit the extent to which low-emission livestock production methods are pursued.

1.2 Implications of demographic, dietary and supply chain transitions for GHG emissions and human health – a livestock story?

Concern with the environmental (including GHG) impacts of livestock production is also related to projections of future demand for livestock products. Projections of demographic and dietary trends point towards increased livestock production and GHG emissions. However, viewed from other perspectives – such as the public health impacts of food consumption – animal-source foods are only one among a number of concerns.

Projections by the United Nations suggest that the world´s population may reach 9.1-9.6 billion by 2050 (UN 2012), and a number of widely cited studies project that current levels of food production will need to increase by about 70% in order to feed the world's population in 2050 (FAO 2009; WRI 2013). In addition to growth in population numbers, it is projected that by 2050 about 70% of the world's population will live in urban areas, and average incomes in many parts of the world are projected to increase significantly, as a greater proportion of the population engages in non-farm employment. Both urbanization and rising incomes are associated with a change in the structure of food consumption – known as the nutrition transition – as diets change from traditional diets high in grains and vegetables to diets based on higher intakes of sugar, fat, animal products and processed foods (Popkin 2003; Kearney 2010; Gill et al. 2015). Figure 2 depicts the annual per capita meat consumption from 1992 to 2010 in various regions in the world. While in many high-income countries the growth in meat consumption has stabilized or reduced, in many low- and medium-income countries meat consumption is increasing.

Different modeling approaches result in significant differences in projected increases in global food demand and demand for animal-source foods (Valin et al. 2014), but all projections point towards a tremendous aggregate increase in demand for livestock products. Projections by the Food and Agriculture Organization of the United Nations (FAO) suggest that, compared to consumption levels in 2005-2007, by 2030 demand for beef, mutton and milk will increase by 54-62%; for pork by 40%, and for poultry meat by 89% (Alexandratos and Bruinsma 2012). There will be regional variation in these trends, with growth in demand likely to be particularly strong for poultry products in South Asia (mainly driven by trends in India), for beef and dairy products in East Asia (mainly accounted for by trends in China) and strong growth for all product types across Africa. The highest growth in total and per-capita consumption of animal-source foods is projected to occur in low and lower middle income countries (Alexandratos and Bruinsma 2012; Robinson and Pozzi 2011). Continued growth is also predicted for oil crops (driven by demand from food consumption, industrial uses and the livestock sector) and sugar crops (Alexandratos and Bruinsma 2012). The potential health impacts of oil and sugar consumption have been highlighted in various studies (e.g. Micha et al. 2014; Singh et al. 2015). These are crop types with large carbon footprints, mainly due to land use change (Plassmann et al. 2010; Flynn et al. 2012).

Alongside agricultural growth, urbanization and rising incomes, the transformation of agri-food supply chains has been observed in many regions of the world (Reardon et al. 2013; Reardon and Timmer 2014). As urban markets become an increasingly important source of food demand, major changes are often observed in how foods are traded, stored, processed and retailed. For example, the development of modern retail outlets, such as supermarkets, depends also on the emergence of other market infrastructure, including wholesale markets, logistics systems and cold chains, road networks, warehouses and packaging sub-sectors. Food processing, including production of ultra-processed foods which combine

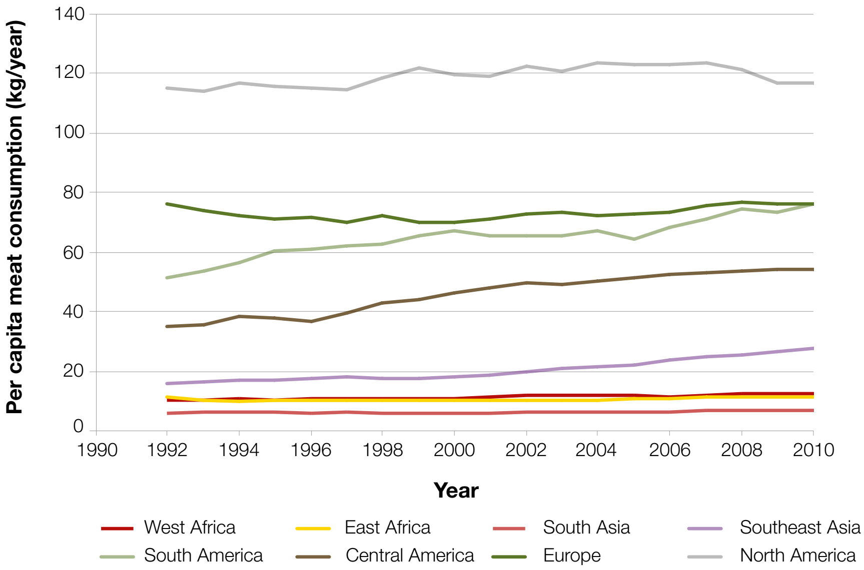


Figure 2. Meat consumption (kg/capita/year) in various regions of the world from 1992-2011.
Source: Adapted from FAOSTAT 2015.

processed ingredients, becomes a more significant source of value added. Such developments are often also accompanied by various forms of vertical integration, such as the emergence of integrated producer-processor enterprises, contract farming and other forms of collaboration between supply chain partners (Reardon 2015). Supply chain transformation is both enabled and driven by changes in on-farm production practices, as farmers invest in infrastructure and production practices that reduce labour requirements, support increased yields or ensure the supply of products meeting retailers' quality requirements.

Agricultural growth has significant impacts on poverty reduction (World Bank 2012), and the trends outlined above have played a significant role in meeting urban and rural food security needs. Yet, there remain approximately 795 million undernourished people (FAO 2015a). Livestock are a key resource for many of the rural poor, and livestock products can make critical contributions to nutrition (Smith et al. 2013a). Meat and dairy products may be an important source of essential dietary nutrients, such as iron, zinc, B-vitamins and calcium (de Beer 2012; Gill et al. 2015). Animal protein provides one third of humans´ dietary protein intake (FAO 2006). At the same time, there is growing awareness that interactions among these trends have significant costs in terms of human health impacts. Urbanization is often associated with lower activity levels, while increased consumption of processed foods, edible oils, sugars and animal products increases energy intake (Popkin et al. 2012). One recent estimate suggests that 2.1 billion people, just under one third of all children and adults globally, are obese or overweight, two thirds of whom live in developing countries (Ng et al. 2014). Obesity rates have been rising particularly rapidly in developing countries in the last decade (ibid). Diabetes and cardiovascular diseases – formerly considered 'rich world' diseases and often associated with the nutrition transition – are now increasingly common in urban (and some rural) populations in developing countries (WHO 2010; Sampson et al. 2013; Kain et al. 2014; Popkin 2015). There is growing concern with the human health burden and potential economic costs of the nutrition transition (Swinburn et al. 2011; Popkin et al. 2012; Popkin 2015).

Globally, per capita food energy availability has increased by 29% in the last 50 years, but per capita energy available from animal source foods has increased by 48% over the same period (Keats and Wiggins 2014). However, increasing food energy intake from animal sources has been particularly notable only in some regions (e.g. East Asia) (Micha et al. 2014). As the studies summarized in Text box 1 show, from a health and nutrition perspective, change in meat consumption patterns is only one among many concerns, including insufficient consumption of 'healthy' foods (e.g. fruit, vegetables, seafood, whole grains) prevalent in many countries. Similarly, studies have also shown that the environmental impacts of nutrition transition vary between countries, and that different food commodities have impacts on different ecosystem services (Gill et al. 2015). In some contexts, the impacts of nutrition transition on other environmental domains (e.g. land use, water, nitrogen and phosphorous cycles) may be a greater concern than its impacts on GHG emissions.

Text box 1. Global food consumption trends

A number of recent studies have improved documentation of global food consumption patterns. Food balance sheets produced by FAO are the most widely used source of data on national food consumption patterns. A recent study compared the food balance sheets with a new global database of dietary surveys, and produced adjusted food intake estimates for men and women of different ages in different countries (Del Gobbo et al. 2015). A further study estimated changes in the consumption of major food groups between 1990 and 2010 (Micha et al. 2014). Some key findings of that study include:

Fruit: Globally, there was only modest increase in per capita fruit consumption, with a statistically significant increase only in South Asia (ca. 3.8 g/day). In 2010 consumption remained below dietary recommendations in 185 of 187 countries.

Vegetables: Globally per capita vegetable consumption remained unchanged, but with large increases and decreases in some countries. In 2010, consumption remained below dietary recommendations in 183 of 187 countries.

Nuts & Seeds: Globally, per capita consumption of nuts and seeds increased, with significant increases in 13 out of 21 regions, including large increases in Southeast Asia, South Asia and Eastern Europe, and large decreases in some sub-Saharan African countries. In 2010, consumption was consistent with dietary recommendations in 26 countries.

Whole Grains: Per capita consumption of whole grains decreased globally, with significant decreases in a number of regions (i.e. Central Africa, South Asia, North Africa and East Asia), and increases only in parts of Latin America. In 2010, consumption was consistent with dietary recommendations in 23 countries.

Fish: There was no increase in global per capita consumption of seafood, with small increases in some parts of Asia and small decreases in some parts of SSA. In 2010, per capita consumption of seafood was consistent with dietary guidelines in 73 out of 187 countries.

Red & Processed Meat: There were significant increases in unprocessed meat consumption in East Asia, and decreases in Argentina, Chile and Uruguay and North America. No region showed significant changes in consumption of processed meats. In 2010 only 5 countries had average per capita consumption levels consistent with dietary guidelines for unprocessed meat, although 55 countries had processed meat consumption levels consistent with dietary guidelines.

Overall, there is considerable diversity between countries in per capita consumption levels for all food groups, and differences in average consumption levels for some food groups between men and women and between age groups. A related study (Imamura et al. 2015) also concluded that both healthy and unhealthy diets were increasing at a global level, with large increases in healthy dietary patterns as well as unhealthy patterns in middle-income countries, and a predominance of worsening trends in some low-income countries in Africa and Asia.

Livestock are not the only concern, either from an environmental or health perspective. However, from an environmental perspective, key justifications for the focus on livestock centre around the extreme inefficiency of livestock conversion of feed, forage and other resources to produce nutrients for consumption, with particularly high water, carbon and nitrogen footprints compared to other food sources (Garnett 2009; Mekonnen and Hoekstra 2012; Nijdam et al. 2012; Bouwman et al. 2013). Given the inefficiency of resource conversion in many livestock production systems, major changes in consumption of livestock products have the potential to dominate the global environmental impacts of agricultural production.

Several studies have assessed the implications of increased consumption of livestock products for GHG emissions and the potential implications of reductions in demand for meat. FAO's modeling suggests that by 2050, global meat production may reach 464 million tons and milk production 1,038 million tons, representing an increase of 73% and 58%, respectively, compared to 2010 (FAO 2011a). Emissions from enteric fermentation associated with this growth are projected to increase by 32% between 2000 and 2050, which would lead to an increase in emissions of more than 2,500 $MtCO_2$eq (Tubiello et al. 2014). Growth in livestock production also has implications for land use. Modeling four alternative diets (i.e. no ruminant meat, no meat, no animal products in which protein from animal products is substituted by plant source protein, and a 'healthy' diet, containing limited amounts of animal products) for the global population, Stehfest et al. (2009) suggests that such changes would greatly reduce future demand for land use and therefore the conversion of high carbon landscapes. A modeling study by Popp et al. (2010) – which simulated a business-as-usual scenario, an increase in meat consumption along with rising per capita Gross Domestic Product (GDP), and a reduced meat consumption scenario in which the share of meat in total caloric intake reduces by 25% per year – estimated that by

2055 agricultural non-CO_2 GHG emissions would increase by 76% in the increased meat consumption scenario compared to the baseline scenario, and decrease by 51% in the reduced meat consumption scenario, with livestock emissions dominating both modeling outcomes. The study estimated that even if meat consumption increases but available agricultural mitigation options are deployed, agricultural emissions will still increase by 13% compared to the baseline scenario. Bajželj et al. (2014) have also projected that even if crop and livestock yields are able to increase at realistic rates, cropland and pastures will need to expand by 42% by 2050 to meet food demand, leading to a 77% increase in emissions from the AFOLU sector. Together, these studies suggest that sustainable intensification of agricultural production will not be sufficient to avoid an increase in GHG emissions from the AFOLU sector, and that demand for livestock products will be a significant driver of increased GHG emissions.

Related arguments supporting a reduction in meat consumption are put forward in a body of literature on 'sustainable diets'.[2] A number of studies have investigated the potential of 'sustainable diets' to promote improved nutrition and human health together with climate change mitigation and the environmental impact of the agri-food system (Pimentel and Pimentel 2003; Stehfest et al. 2009; Wirsenius et al. 2011; González et al. 2011; Vanham et al. 2013; Hallström et al. 2014; Sabaté and Soret 2014; Tillman and Clark 2014). These studies reflect a variety of dietary guidelines or assumed diets, which range from reducing animal source foods to completely eliminating animal source protein and replacing it with plant-based alternatives (e.g. Van Dooren and Kramer 2012; Garnett 2014; Van Kernebeek et al. 2014; Auestad and Fulgoni III 2015; Green et al. 2015; Röös et al. 2015). Despite differences in dietary and modeling assumptions, the vast majority of such studies suggest that there may be synergies between health objectives and GHG mitigation objectives (Hallström et al. 2014; Auestad and Fulgoni III 2014). Such studies have often been conducted with relevance to diets and populations in developed countries, where evidence also suggests that healthier diets may be more costly than less healthy diets (Rao et al. 2013), which along with knowledge, accessibility and other factors most likely presents a barrier to adoption of healthier diets.

In this context, a number of studies have analysed the potential effects of consumption taxes on animal products. A study by Wirsenius et al. (2011) analysed the potential effects of a consumption tax on animal products in the European Union (EU), where taxes would increase the price of ruminant meat by 16% and poultry products by 4%. That study estimated that EU GHG emissions from the agricultural sector could be reduced by between 7% and 36%. Another modeling study focusing on Sweden predicted that if differential taxes (ranging from 8.9-33.3%) were applied to meat and dairy products, national emissions from the livestock sector would decrease by up to 12% (Säll and Gren 2015), while a study of differentiated taxes applied in Denmark suggested potential GHG emission reductions of 10.4-19.4% (Dhyr Edjabou and Smed 2013), along with various co-benefits, such as reduced water footprints and pollution, reduced nutrient leaching and additional health benefits (Dhyr Edjabou and Smed 2013; Säll and Gren 2015).

1.3 Waste reduction in agri-food supply chains

Food loss and waste[3] in agri-food supply chains represent another critical area of concern related to the agri-food system, with major implications for resource use efficiency across the entire food supply chain. Resources such as land, water, energy and inputs (e.g. fertilizer) utilized throughout food supply chains are lost or wasted, and yet still produce GHG emissions (Smith 2013). For example, in 2009 food loss and waste was thought to be responsible for an estimated 3,300-5,600 $MtCO_2eq$ of global GHG emissions (CGIAR n.d. in Lipinski et al. 2013), the use of 173 billion cubic meters of water, and the use of 28 million tons of fertilizer (Kummu et al. 2012). Substantial economic losses are also associated with food loss. For example, in sub-Saharan Africa (SSA), food losses are thought to be responsible for economic losses up to USD4 billion per year (World Bank et al. 2011). These losses have major implications for food security and livelihoods (Tefera 2012; GIZ 2013), as the food losses reported are estimated to be sufficient to feed 1 billion people. Consumers in areas with high-food losses may experience reduced food availability, decreased nutritional quality (e.g. from poor storage conditions), increased food safety risks and increased prices. At the same time, depending on where they happen in the supply chain, food losses can also represent foregone income for producers or processors (FAO 2011b). It has been estimated that reducing food loss and waste by half could provide 20% of the gap in calories between currently available calories and the estimated demand in 2050 (WRI 2013). Reduction in food loss and waste has therefore been identified as a necessary step to address the gap between current food production and future estimates of food demand (HLPE 2014).

[2] Sustainable diets have been defined as "…diets with low environmental impacts which contribute to food and nutrition security and to a healthy life for present and future generations" (FAO 2012, p.264).

[3] **Food losses** have been defined as "a decrease, at all stages of the food chain prior to the consumer level, in mass, of food that was originally intended for human consumption, regardless of the cause", while **food waste** "refers to food appropriate for human consumption being discarded or left to spoil at consumer level – regardless of the cause" (HLPE 2014).

While several studies have shown that substantial food loss and waste occurs throughout every stage of the agri-food supply chain (FAO 2011b; Lipinsky et al. 2013; Affognon et al. 2015), there are numerous challenges in quantifying food loss and waste. Definitional issues abound, such as distinctions between avoidable and unavoidable waste, which vary between countries and food cultures. Comprehensive and comparable data on food loss and waste throughout commodity supply chains is generally lacking in most countries (Hodges et al. 2010; Parfitt et al. 2010; IICA 2013; Affognon et al. 2015). The lack of data is a critical limitation on the political visibility of the issue, on the identification of key stages in supply chains, and on the design of interventions to reduce waste and losses.

The most comprehensive study on global food loss estimates that approximately one third of the food produced for human consumption - equivalent to 1.3 billion tons of food per year - is lost or wasted (FAO 2011b). Kummu et al. (2012) estimate that this equates to approximately 15% of the total global food energy supply. Roughly 55% of these losses occur in developed countries, with the remaining 45% in developing countries (FAO 2011b; Lipinsky et al. 2013). On a per capita basis, there is substantially more food loss and waste in developed countries. For instance, in North America per capita food loss and waste amount to 95-115 kg per person per year, while in SSA and South and Southeast Asia the figure is about 6-11 kg per person per year (FAO 2011b). However, there are significant differences between countries and commodities in levels of waste and loss (Figure 3). Among food commodity types, when measured by energy value (kcal), the largest contributor to total global losses and waste arises from cereals, followed by roots and tubers, fruits and vegetables, oilseeds and pulses, meat and milk, but when measured by weight fruits and vegetables account for the majority of food loss and waste, followed by roots and tubers, cereals, and milk (Lipinski et al. 2013).

Food loss and waste can occur at every stage of the agri-food supply chain (agricultural production, post-harvest, processing, handling and storage, distribution and consumption). As illustrated in Figure 4, in developed countries, the majority (i.e. 40-60%) of food loss and waste occurs in the consumption stage, while in developing countries most losses occur during the post-harvest, processing, handling and storage, and distribution phases, with loss and waste at the consumption stage accounting for between 5-34% of total losses and waste (FAO, 2011b; Lipinski et al. 2013). This pattern in developed countries is linked to various factors such as the overproduction and

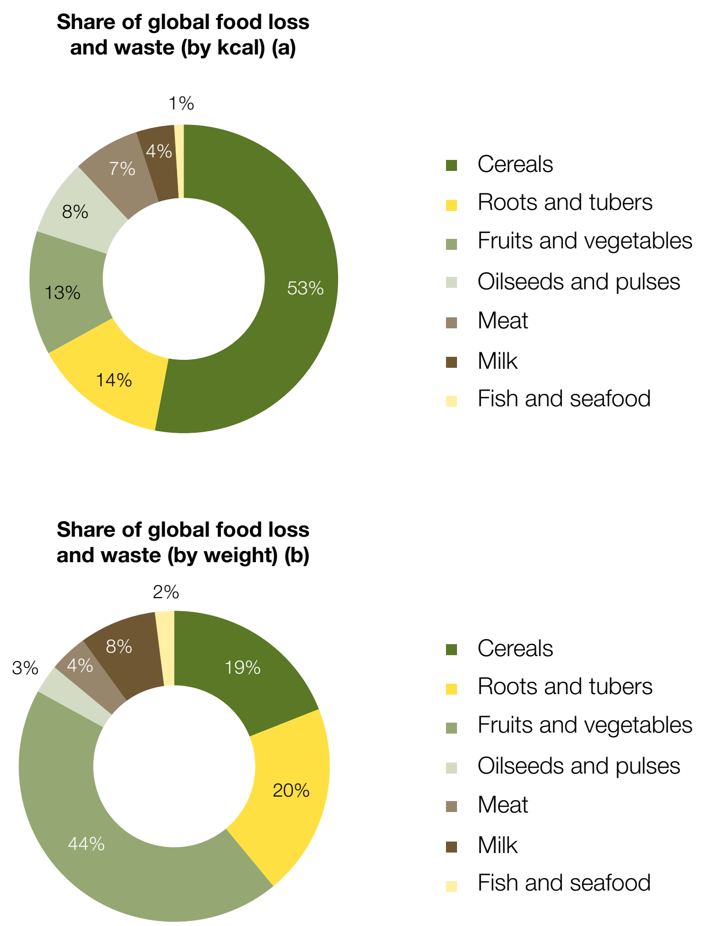


Figure 3. Share (%) of food loss and waste per commodity based on (a) kilocalories, and (b) weight (billion tons).
Source: Adapted from Lipinsky et al. (2013) and FAO (2011b).

abundance of food (supply greatly exceeds demand), the common attitude that it is easier to dispose of food than reuse food, high appearance quality standards (e.g. set by retailers), and consumer affordability, while in developing countries, lower levels of food waste in the consumption stage are generally related to household purchasing power and the higher cost of losses and waste relative to incomes (FAO 2011b). In developing countries, for most commodities higher losses occur during the post-harvest handling and storage, processing and packaging and distribution stages due to damage by pests (insects, birds, rodents) or tools, climatic conditions, micro-organisms, respiration and transpiration associated with limited packaging, handling / physical damage (e.g. bruising of fruit), and spillage (Guillou and Matheron 2014). Secondary factors that influence food loss during the supply chain include insufficient capacities and technical expertise, lack of necessary resources (e.g. equipment, packaging), inadequate or lack of infrastructure (e.g. storage facilities, roads), extreme climatic events (poor drying season), product standards and product grading systems (e.g. to ensure that only standardized products reach the retail stage), and unfavourable market conditions (e.g. low prices) (Guillou and Matheron 2014).

The supply chain transformations ongoing in many developing countries can therefore influence food loss and waste in both positive and negative ways. Where supply chains are well functioning and integrated, waste and losses before the consumption stage may be reduced. For example, a study of losses in milk supply chains in Kenya found that 5% of milk is wasted on-farm due to spoilage of milk produced in the evenings that is not sold, while further losses occur at milk collection centres due to rejection of poor quality milk (Muriuki and Kiio-Mutua 2014). In this case, increasing rainy-season road access to milk collection points, sales of evening milk (e.g. by reducing distance to milk collection points) and stronger support by processors for supplier compliance with milk quality standards can reduce losses. As agri-food supply chains evolve, hotspots of waste and losses will shift. Some supply chains seek to maintain quality requirements while others do not, shifting the flow of agri-food produce, waste and losses between marketing channels. Processing activities may increase, but new forms of waste may be produced by inefficient processors, shifting waste and losses down supply chains. And if, as in China, urban middle classes increasingly eat out, the physical location of waste may shift to restaurants and other catering establishments (Liu et al. 2013).

Some studies have estimated the theoretical mitigation potential of measures to reduce food loss and waste. Bajželj et al. (2014) modeled future scenarios for 2050, based on a population of 9.6 billion people and an increasing nutrition transition in developing countries based on current observed trends, and estimated that if current levels of food loss and waste were halved, GHG emissions in 2050 would decline by 22-28% from current levels, and that cropland would be reduced by approximately 14%. Smith et al. (2013b), assuming a 6% reduction in waste and losses throughout the food supply chain, suggests that the technical mitigation potential of reductions in food loss and waste is between 5,200 and 18,900 $MtCO_2eq$ per year. However, it has also been pointed out that price effects of reductions in waste are rarely captured in modeling exercises. For example, if waste is reduced, for a given price, demand will also reduce because less is wasted. Prices will adjust to the decreased demand, but the resulting change in demand will be less than the reduction in waste because lower prices will stimulate a certain amount of non-wasteful demand (Revell 2015). One study has also suggested that reduced prices may also be transmitted to developing countries following reductions of food waste in developed countries (FAO and LEI Wageningen 2015).

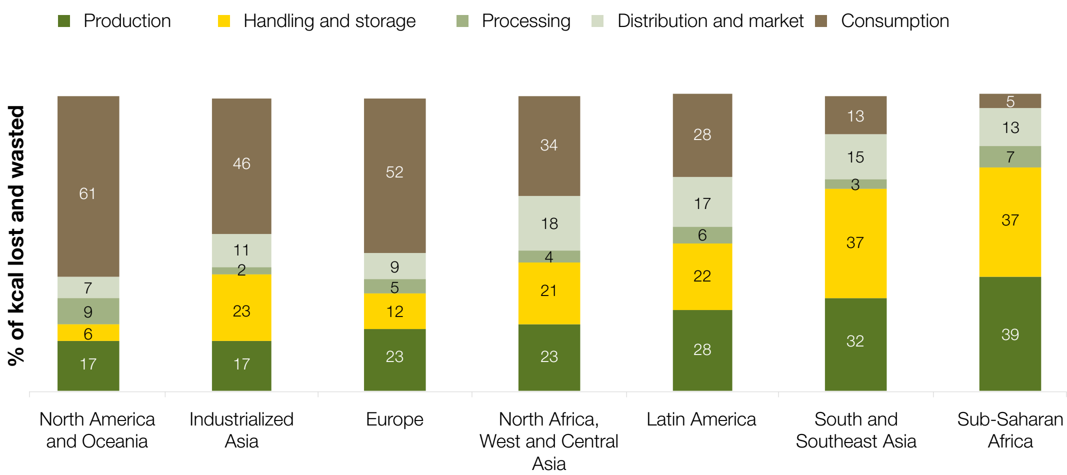


Figure 4. Percentage (%) of kilocalories (kcal) lost and wasted throughout the agri-food supply chain in different regions of the world.

Source: Adapted from Lipinsky et al. (2013).

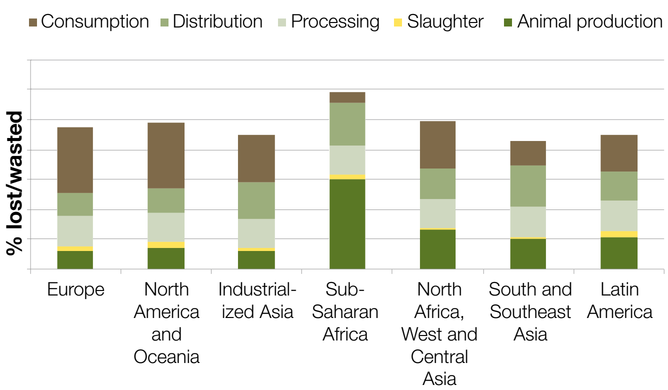
While meat and dairy account for relatively small proportions of total global losses by weight and food energy value, meat and dairy products are generally associated with higher resource requirements and have larger environmental impacts, in terms of land and water requirements, and GHG emissions. FAO (2015b) has estimated that although meat accounts for less than 4% of food loss and waste by weight, it accounts for approximately 20% of the global carbon footprint of food loss and waste. At a global level, from a GHG perspective, cereal, vegetable and meat losses and waste are the main hotspots, accounting for more than 70% of the global carbon footprint of food loss and waste (ibid.). One study estimated that losses and waste of meat and dairy products in the USA account for more than 50% of the total carbon footprint of food loss and waste in the country, although these product groups only account for 27% of total losses and waste by weight (Venkat 2012). Available data suggests that the key supply chain stages vary between regions for loss and waste of meat and dairy products (FAO 2011b). Figure 5a indicates that in developed regions, losses and waste of meat mainly occur at the consumption stage, while in developing regions losses and waste in production and distribution are relatively more important. In particular, animal mortality due to diseases in SSA is highlighted as a major cause of meat products lost from the food system. A similar pattern is also suggested for dairy products (Figure 5b), whereby most losses in developed regions occur in consumption, while in developing regions post-harvest losses and distribution are relatively more important.

1.4 The state of debate

The technical mitigation potential of supply-side agricultural mitigation options is considerable (Smith et al. 2014), but although many agricultural mitigation options are well known, there are also many barriers to adoption, including in some situations significant barriers that cannot be addressed by finance alone. Recent studies have also suggested that with a growing demand for food and for livestock products in particular, deploying available mitigation options may be insufficient to prevent an increase in GHG emissions from agricultural production and associated land use changes (e.g. Bajželj et al. 2014; Hedenus et al. 2014). Attention has begun to focus on the potential of demand-side measures to reduce food loss and waste and to promote dietary change. The IPCC's Fifth Assessment Report estimated that the technical mitigation potential of these demand-side measures was even greater than the mitigation potential of supply-side measures (Smith et al. 2014; Smith et al. 2013b). This suggests that, in order to avoid increases in absolute GHG emissions from agricultural production, both supply- and demand-side measures should be deployed.

Despite the interest of many countries in implementing agricultural mitigation options (Richards et al. 2015), to date climate finance investments in agriculture have been limited (Wilkes et al. 2013). Anecdotal evidence suggests that the importance of demand-side measures has been rapidly taken up in discussions in international forums and is influencing some investment decisions of climate finance institutions. It is therefore timely to assess the extent to which demand-side mitigation policies and measures are readily available for deployment. This is the purpose of the chapters that follow.

(a) Meat



(b) Dairy products

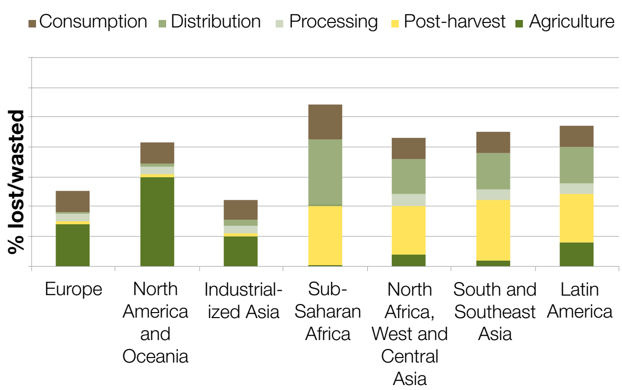


Figure 5. Losses and waste of (a) meat and (b) dairy products by supply chain stage and region.
Source: Adapted from FAO (2011b)

2. The evidence on demand-side mitigation interventions

Modeling studies have highlighted that demand-side measures will be necessary, and have suggested that demand-side measures have a significant technical potential to mitigate GHG emissions (Smith et al. 2013b; Bajželj et al. 2014; Smith et al. 2014). To date, there has been little systematic analysis of available evidence on whether this technical potential is feasible in economic, social and political terms. The main demand-side measures discussed in the modeling literature are reductions in food waste and dietary change. The following subsections introduce some of the main types of interventions, available evidence on their effectiveness and associated challenges.

2.1 GHG mitigation through dietary change

Most modeling studies estimating the effects on agricultural GHG emissions employ scenarios that assume certain diets (e.g. meat, less meat, no meat with replacement by plant proteins), but do not model measures for achieving dietary changes. The exceptions are the few studies that focus on the modeled effects of meat taxes (e.g. Wirsenius et al. 2011; Säll and Gren 2015; Dhyr Edjabou and Smed 2013). Large-scale dietary change is not a straightforward process. Food consumption behaviour is affected by a number of factors, including economic factors such as price and affordability, as well as preferences, norms and habits, which may be related to geography, culture, religion, disposable income, socio-economic status, urbanization, globalization, marketing, and so on (Kearney 2010; Font-i-Furnols and Guerrero 2014; Gill et al. 2015). The role of prices and affordability is often thought to be paramount in the decision-making process for consumers, and thus many studies have focused on the potential of subsidies or taxation to promote dietary change (Wirsenius et al. 2011). To date, there have been relatively few examples of food subsidies or taxes to incentivize more sustainable diets. Health promotion and education are the most common settings in which dietary change is promoted. Health promotion initiatives may include public-awareness campaigns, clinician advice, school-level nutrition and health initiatives or product labeling (Capacci et al. 2012). The following sections review the evidence on these 'hard' and 'soft' measures to promote dietary change.

2.1.1 Consumption subsidies and taxation to promote sustainable diets

The theoretical basis for subsidy and taxation measures

The rationale for applying taxes to unhealthy or unsustainable foods or providing subsidies for foods with less adverse health or environmental impact is the effect of price on consumption decisions. Taxes or subsidies can change the product price, which should provide incentives to consume more or less of a targeted food. The effect of taxes or subsidies depends in part on the price elasticity of demand for specific food types.[4] A high own-price elasticity of demand means that as the price increases, the consumption of the product decreases, while a low own-price elasticity of demand means that consumption would be less responsive to a change in price. The magnitude of consumption response to a change in price also depends on whether the product is perceived as a necessity good, such as a staple part of the diet, or a luxury good; the proportion of total budgets accounted for by the good; and the availability of substitute goods. The overall effect on the GHG emissions associated with dietary change will also depend on cross-price elasticities, which measure the extent to which an increase in the price of one product leads to a change in the consumption of another product.

In general, empirical research finds that own-price elasticities for food product categories decrease as average per capita GDP increases (Green et al. 2013). This suggests that for a given percentage increase (decrease) in product price due to a tax (subsidy), consumers in developed countries (where the highest per capita consumption levels generally occur) would be relatively less responsive than consumers in less developed countries. Since income elasticities for meat products are typically below 0.5 (FAPRI 2015 in Revell 2015), this also suggests that as average per capita incomes in developing countries rise over time, consumer response to a uniform tax (or subsidy) would most likely weaken. When comparing across households at different income levels, own-price elasticities of food product types are also smaller for wealthier households than for poorer households (Green et al. 2013), suggesting that a uniform tax (or subsidy) on consumption of a food product type in a country may have a greater impact on lower income households than on higher income households, while higher levels of per capita consumption and 'over-consumption' of high GHG-intensity products are more likely to occur among higher income households.

[4] An 'own-price' elasticity measures the per cent change in demand for a product for a one per cent change in its price, while a 'cross-price' elasticity measures the change in demand for a product if the price of a related product changes. An 'income elasticity' measures the response of demand to a one per cent increase in income. Elasticities are expressed as a proportion, and goods with a price elasticity of less than 1 (in absolute terms) are considered to be inelastic.

Data on cross-price elasticities within food products is very sparse, preventing a general assessment of substitution effects. It should also be noted that, while economics provides a comprehensive basis for the analysis of price effects, prices have been found to be insufficient to account for consumers' food purchasing decisions, suggesting that other, non-price factors also inform consumer preferences (Dubois et al. 2013).

Evidence on taxation and subsidies

A number of studies have been conducted in recent years on the possible effects of taxation and subsidy policies on consumption of food types associated with adverse health and/or GHG effects, some of which are summarized in Table 1. The majority of published studies are based on analysis of large-scale household surveys, model simulations or experimental studies in laboratory or 'real world' situations. Where data derive from 'real world' experimental studies, these have often been restricted to specific food purchase or consumption contexts, such as institutional canteens, supermarkets or vending machines (Epstein et al. 2012). There are few empirical studies of large-scale public policy interventions (aside from agricultural production subsidies, which have quite different effects from consumption subsidies – see Text box 2). While a few studies included the effects of taxation and subsidies on dairy products, there have been almost no empirical studies on interventions specifically targeting meat consumption. There are also very few studies focusing on developing countries, where the largest increase in future meat and dairy consumption is expected to occur. The current evidence base for recommending taxation or subsidy policies to promote dietary change in developing countries is therefore very limited.

In general, studies on subsidies to healthy foods (e.g. through price discounts or purchase vouchers) find that a subsidy increases purchase and consumption of targeted foods. A systematic review of 20 studies by An (2013) found that in all but one study subsidizing healthier foods was effective in significantly increasing the consumption of targeted food types, such as fruit and vegetables or healthy snacks. Seven subsidy studies reviewed by Thow et al. (2014c) also found that subsidies (ranging between 1.8% and 50%) promoted consumption of targeted foods, but noted that the effect on total calorie intake was unclear, with some studies reporting an increase in overall food consumption, rather than a substitution between food groups.

Table 1. Summary of studies included in selected meta-analysis or reviews of the effects of taxation and subsidy measures on food consumption or related health outcomes

Meta-analysis	Objective	Number of studies included	Types of study included	Food product types included	Location
Powell & Chaloupka 2009	Effect on body weight	21 studies	Non-intervention price elasticity studies	Sugar-sweetened beverages, fast food, fruit and vegetables	USA
An 2013	Effect of subsidy on purchase or intake	24 articles (20 experiments)	Pre-post study, Randomized controlled trials (RCTs), cohort studies	Fruit & vegetables, low-fat snacks, healthy drinks (incl. milk)	Developed countries (n=19), developing country (n=1)
Thow et al. 2014c	Effect on food or nutrient consumption	43 papers (38 studies)	RCTs, modeling studies, stated preference survey	Various	Developed countries (n=37), developing country (n=1)
Maniadakis et al. 2013	Effect on consumption, caloric intake or body weight	55 studies	Experiments, surveys, modeling studies	Sugar-sweetened beverages, and high-in-fat, salt, and sugar foods	Developed countries (n=52), developing countries (n=2)
Eyles et al. 2012	Effect on purchase or intake and health	32 studies	Modeling	55 specific food types, incl. dairy products (n=5) and meat (n=1)	OECD countries

Most studies on the effect of taxation have focused on sugar-sweetened beverages and high fat, salt and sugar foods, which are particularly associated in many countries with obesity. A meta-analysis focusing on the price elasticity of foods related to obesity in the USA (Powell and Chaloupka 2009) suggested that existing state taxes, which are mostly below 5%, are insufficiently high to result in significant changes in key indicators of obesity in the general population. They did report, however, some positive outcomes in certain sub-groups, including youth and lower socio-economic classes, where taxation on unhealthy food combined with subsidies on healthy food (e.g. fruits and vegetables) was correlated with some desirable weight loss. Another study suggests that taxes on sugary drinks should be at least 20% - a much higher tax rate than currently applied – in order to be effective in reducing obesity (Mytton et al. 2012). Sixteen studies reviewed by Thow et al. (2014c) that modeled the effect of taxes (ranging between 5% to 30%) on consumption of sugary drinks showed a reduction in consumption of the targeted products of 5% to 48%, with a greater effect on consumption by adults than consumption by children. However, the effect on total calorie intake was also unclear, with some studies reporting overall reductions and others reporting no reduction due to substitution effects. Studies focusing on the effect of taxes (5% to 17.5%) targeting fat content of food show some potential to incentivize substitution to low-fat options (with decrease in saturated fat consumption by 0-3%), but some studies suggest a potential for other effects, including a decrease in consumption of some healthy food items (Thow et al. 2014c). Prospective and modeling studies on the effect of taxes (10% to 50%) on 'unhealthy' or 'junk' foods have found significant decreases in purchase and consumption of targeted foods, including among obese participants (ibid). However, other reviews find that the resulting effects on body weight or energy intake are mostly small or statistically insignificant (Maniadakis et al. 2013), and highlight the heterogeneous and incomplete evidence on the effects of food consumption taxes (Capacci et al. 2012).

Text box 2. Agricultural production subsidies and the price of food

If consumers are responsive to relative prices, and if different meat products have different GHG intensities (Opio et al. 2012; MacLeod et al. 2013), would it not be an option to increase the supply of lower GHG intensity products (e.g. poultry, fish) through subsidies to producers?

Firstly, that depends on whether consumers see different meats (e.g. beef and chicken) as substitutes. This can be assessed from cross-price elasticities, which have rarely been estimated for meat products. There is no global database of cross-price elasticities for meats, although some studies in developing countries have established that poultry and other meats are substitutes in those countries (e.g. Resende Filho et al. 2011; Bett et al. 2012).

Secondly, it depends on whether the subsidy is passed on from the producer price to the retail price faced by consumers. Some studies of poultry prices in developing countries do indicate that producer and retail prices move closely together (e.g. Mkhabela and Nyhodo 2011), while others have found that they do not (e.g. Hoppe 2008). The presence of asymmetrical price movements in agri-food supply chains has been found to be related to supply chain structure and governance (Bakucs et al. 2013). Where producers or retailers have significant market power, and in particular where regulations (e.g. restrictions on market entry or imports) limit competition in the sector, producer prices are less likely to be rapidly and directly transmitted to retail prices (ibid; Digal 2010; Barahona et al. 2014).

Thirdly, subsidies (or other regulation to protect subsidized supply chains) distort competitive markets. This may lead to inefficient allocation of capital towards the promoted supply chain, and can distort competition among suppliers. For example, backyard chicken production is an important source of nutrition and income for vulnerable groups (e.g. poor, women) in many developing countries, although it only produces a small proportion of global poultry meat and egg supply (MacLeod et al. 2013). Yet, support to larger farmers or industrial producers might strengthen their competitive advantage over small producers, or lead to smallholders' exclusion from urban marketing chains (Ifft et al. 2008).

Fourthly, even if subsidies were able to support a viable poultry industry, it does not follow that this would represent a net benefit to society. Consumers may benefit from a lower price, and producers may benefit from a lower marginal cost of production, but the net cost is borne by taxpayers and causes a net loss of welfare to society (known as 'deadweight loss'). Similarly, import restrictions to protect the domestic poultry market may cause a net loss of welfare to consumers, despite the growth of the domestic industry (Grynberg and Motswapong 2011).

Finally, there may also be trade-offs between a reduced GHG footprint and other environmental impacts. A wide range of impacts should be considered when assessing the net costs and net benefits of taxation or subsidy policies.

There are therefore several potential challenges to effective supply-side subsidies, and this option is not considered further in this report.

Beyond taxes on sugary drinks, which are applied in some US states and elsewhere (e.g. Mexico), large-scale public policy interventions have included the Danish 'fat tax' (see Text box 3), a public health food tax in Hungary, and a sweet tax in Finland. Overall, there is insufficient understanding of the effects of food taxes in practical situations to be able to assess their effects with confidence (Cornelsen et al. 2014). Firstly, few of the existing studies have focused on core elements of diets, such as dairy products or meat. Consumer response to taxes on non-necessities will be different to responses relating to foods perceived as necessities. Secondly, the existing literature highlights the importance of substitution effects to overall policy outcomes. These effects are insufficiently understood, but have the potential to prevent the achievement of policy objectives and may have other unintended adverse effects on health or environmental outcomes. Thirdly, responses to a price increase differ between different social groups. In general, the average household in developing countries spends a greater proportion of its income on food, and poorer households spend more on food (and in some cases purchasing more of specific types of 'unhealthy' foods) than wealthier households. More specifically, dietary patterns vary considerably within populations and population sub-groups. The effects of a tax on particular groups (e.g. people at risk from a targeted health condition) may differ from the effects on other groups. The distributional effects of food taxes will therefore be complex, and food taxes may also have regressive income impacts (Ng et al. 2008; Capacci et al. 2012; Epstein et al. 2012). Fourthly, responses of and impacts on the agri-food sector are unclear. For example, manufacturers have been found to react to taxes on sugary drinks by changing their use of inputs, substituting less healthy sweeteners (Cornelsen et al. 2014), and supermarkets may absorb some of the tax rather than pass it on to consumers (Berardi et al. 2012). Overall, the effects on agri-food sector competitiveness are complex and unclear (ECORYS 2014). As noted above, there has been very little analysis on the effects of food taxes on consumers and producers in developing countries, where most of the future increase in consumption is expected to occur (Niebylski et al. 2015). Fifthly, there is a risk of political backlash from consumers and industry. While a recent study based on focus group discussions in a number of developed and developing suggests the political risks are overestimated (Wellesley et al. 2015), politicians are likely to be risk-averse, which may increase the political difficulty of implementing effective policies to change consumer behaviour. To the extent that taxes or subsidies to change consumer demand may be motivated primarily by concern with the carbon cost of animal product consumption, it is worth noting that at a carbon price of USD20/tCO_2, the implicit tax rate equivalent to 11-23% of 2010 ruminant meat prices, while a carbon price of USD50/tCO_2 would imply a tax rate of 28-56% of 2010 ruminant meat prices, and such high tax rates would have significant political ramifications (Revell 2015).

Text box 3. Experiences of Denmark's 'fat tax'

The Danish 'fat tax' is one of the few examples beyond sugary drinks where taxes have been applied to food. From October 2011 until January 2013, Denmark implemented a tax on food products that were considered high in saturated fats (>2.3%), which included meat and dairy products. The Danish 'fat tax' caused a substantial backlash from some experts, the food industry and the general public and was critiqued for its poor design. Experts critiqued the tax for not being high enough to actually influence behaviour, and stated that there was an emphasis on tax revenue over public health benefits (Bødker et al. 2015a; Bødker et al. 2015b). Food-industry lobbying groups attacked the tax stating that it put Danish jobs at risk and damaged the overall competitiveness of the Danish food industry (Bødker et al. 2015a; Bødker et al. 2015b). During its brief implementation, cross-border shopping increased where products were bought in neighbouring countries where they were more affordable (e.g. Germany, Sweden; Bødker et al. 2015a; Bødker et al. 2015b). However, research did identify a significant impact on total consumption of saturated fat and a reduction in related heart disease risks (Toft et al. 2014). While this tax was not focused on climate objectives, Dhyr Edjabou and Smed (2013) estimated that an efficient application of the tax might decrease the carbon footprint of food for the average household by 2.3% to 8.8%.

2.1.2. Soft measures to promote sustainable diets

Food consumption behaviour is not only influenced by relative prices. A host of other factors, often not well understood, also influence consumer behaviour in different contexts. Consequently, a variety of interventions are potentially relevant in initiatives to promote sustainable diets. These include health education to influence knowledge, perceptions and beliefs (and restrictions on marketing of 'unhealthy foods'); environmental interventions, such as provision of healthy foods in schools, or restrictions on advertising; and product interventions, such as GHG labeling and packaging requirements. Public health policies aimed at influencing consumer behaviour may use a combination of interventions targeting these dimensions, sometimes also in combination with the subsidy or tax measures described in the previous section. Here, we examine the evidence on three types of interventions that could potentially aim to influence dietary choice: public health education and other health promotion initiatives, restrictions on marketing of 'unhealthy' foods, and product labeling.

Evidence on health promotion

Nutritional education and public awareness campaigns are the most prevalent types of measures adopted to promote changes in food consumption (Capacci et al. 2012). These campaigns can be developed by diverse actors ranging from governments, civil society organizations and the private sector. They may focus on diet alone, or they may address a range of risk factors associated with health conditions, such as diet, activity levels and other factors. In terms of interventions, health education may consist simply of provision of information, or information provision may be integrated with other measures designed to enable and encourage the promoted lifestyle change, such as attendance at advice groups. Common types of health promotion initiative include clinician-, community-, workplace- or school-based initiatives, and in developed countries many such initiatives target diet-related conditions such as obesity, diabetes and cardiovascular disease.

While nutrition-related public awareness campaigns have been found to influence knowledge and attitudes, there are both challenges with measuring their effectiveness and with interpreting their possible implications for the GHG footprint of the resulting dietary changes. Relatively fewer studies have linked such initiatives to actual measured changes in health outcomes (Capacci et al. 2012). Close monitoring of diets is also difficult, so even where studies are able to link participation in an initiative to changes in health outcomes, evidence on how diets actually change may be absent. Here, we report the results of reviews of initiatives to promote vegetable and fruit consumption and to address obesity, as well as school-based initiatives.

An early review of initiatives to promote intake of fruit and vegetables in selected developed countries (Ammerman et al. 2002) estimated that more than three quarters of the studies reviewed reported significant increases in fruit and vegetable intake (average of 0.6 servings per day, compared to a total recommended daily intake of 7-8 servings). The review suggested that interventions are more successful where populations at risk or diagnosed with chronic disease are targeted, a finding also supported by a subsequent review that found more variable effectiveness of initiatives to increase intake of fruit and vegetables (Pomerleau et al. 2005). A review of six national campaigns in developed countries to promote fruit and vegetable consumption also showed variable results, and concluded that "the campaigns have overall resulted in increased awareness and some modest gains in consumption over the short term but significantly, despite the tremendous cost and effort put into these campaigns, most have been unable to realize the target levels for consumption over the longer term" (Rekhy and McConchie 2014). Evidence for the cost-effectiveness of these campaigns is also limited (Cobiac et al. 2010). A more recent systematic review of US studies of behavioural interventions to increase fruit and vegetable intake (Thomson and Ravia 2011) reported increases in consumption among a variety of target groups, but also cautioned that the behavioural interventions studied were not sufficient to sustain higher levels of intake. A review of factors affecting sustained change in diet and physical activity (Fjeldsoe et al. 2011) found that interventions targeting specific groups (e.g. women), that had a longer duration of the intervention, involved face-to-face contact, and used more intervention strategies were more likely to achieve sustained change. There have been fewer studies of interventions specifically targeting reductions in saturated fats (for which meat and dairy is a main source) or total fat, presumably because evidence suggests that low-fat diets are no more effective in reducing body weight than other diets (Pirozzo et al. 2003; Sacks et al. 2009). No study of interventions specifically targeting reduction in meat consumption was identified.

Apart from targeting intake of specific foods, health interventions also target the risk of lifestyle-related health conditions such as obesity, diabetes or cardiovascular disease, or any combination of these, commonly through promotion of dietary change and physical activity. Dietary measures to reduce obesity commonly focus on restricting caloric intake, which will most likely imply a decrease in the carbon footprint of food consumed. A study comparing the effects of different dietary recommendations suggests that a range of specific dietary recommendations may achieve similar effects on key indicators such as body mass index (BMI) (Sacks et al. 2009). In that study, different diets achieved reductions of about 20% in calorific intake and percentage of saturated fat in diet, resulting in reductions in body weight of 3-4 kg after 2 years. Reviews of the effectiveness of community-based interventions show similar results, with moderate effects of measures to promote physical activity or improve diets or both (Miller et al. 1997). A systematic review of 36 community programs promoting physical activity and dietary change to reduce the risk of cardiovascular disease found that most evaluations reported net positive but mostly insignificant improvements in indicators of cardiovascular disease risk (Pennant et al. 2010). Due to the difficulties of monitoring dietary intake, studies are generally not available that would enable quantification of dietary change and the consequent GHG effects attributable to such interventions.

Overweight, obesity, diabetes and pre-diabetes have been rising particularly rapidly among children in both developed and developing countries (Ng et al. 2014, Popkin 2015). Nutritional education in schools has been found to be effective in influencing attitudes, and there is evidence showing that it has the potential to influence behaviours (Capacci et al. 2012). For example, in Mexico educational programs were developed to reduce obesity in primary schools, where after 3 years students who participated in the program had a BMI that was lower by 0.3 Kg/m2, while the total consumption of total calories, bread, fat and sugars within schools also decreased (Alvirde-García et al. 2013). A study in Kenya determined that caregivers´ education levels were correlated with the nutritional status of children, and that improving nutritional education for caregivers is an important intervention strategy to improve nutrition (Bukania et al. 2014). Many studies have shown behavioural change is possible from nutrition-related educational campaigns, however it is often limited to minor improvements (Capacci and Mazzocchi 2010; Capacci et al. 2012; Alvirde-García et al. 2013; Schembri et al. 2016). Furthermore, different sub-groups (e.g. socio-economic status, age, gender, etc.) may respond to educational measures differently, and it is important to understand how educational programs target different groups (e.g. Capacci and Mazzocchi 2010). While the amount of literature on educational interventions is much greater on interventions in developed countries, there is a growing evidence base of similar interventions in developing countries as many countries are recognizing the importance of nutrition-related education to reduce diet-related non-communicable diseases (e.g. Alvirde-García et al. 2013; Kain et al. 2014).

There have been positive results from studies which indicate that school gardening programs may be effective in improving diets and nutritional education (FAO 2010; Berezowitz et al. 2015; Davis et al. 2015). This includes improving diversity within diets to include more fruit and vegetable consumption (Berezowitz et al. 2015; Davis et al. 2015), and enhances nutritional education while also improving attitudes towards the environment (FAO 2010). FAO (2010) further emphasizes that school gardening also improves understandings of horticulture and garden management providing important horticultural and entrepreneurial skills, which can further support agricultural dependent communities. There is a general consensus that nutritional education is an important element within a diverse policy package, although on its own its ability to influence behavioural change is thought to be limited (Capacci et al. 2012; Lara et al. 2014; Garnett et al. 2015; Schembri et al. 2016). Another source of information affecting dietary choices is commercial advertising. Many countries have promoted voluntary measures to limit advertising of 'unhealthy' foods, especially on TV during times when children are likely to be watching. One review analysed the reported effectiveness of such measures in both the peer reviewed literature and in industry reports and found that while industry reports suggest a high level of adherence with the voluntary codes or regulation, peer reviewed literature indicates that such advertising shows no or little change, with children often continuing to be exposed food advertising (Galbraith-Emami and Lobstein 2013). The effect on food consumption was not measured in these studies, but continued industry investment in advertising would seem to imply that regulatory efforts to restrict advertising to children are likely to have little impact on consumption levels.

Evidence on product labeling and certification

Product labelling is another common way of providing information to consumers in order to promote behavioural change towards sustainable healthy diets. The result of assessments of the effectiveness of product labelling is varied. Systematic reviews have found that most consumers read nutritional labelling, although it is not always used or understood, and that children, adolescents and obese adults are less likely to make use of the information in nutritional labelling (Cowburn and Stockley 2004; Campos et al. 2011). Price, taste, convenience, and habit are often more important determinants of food purchasing decisions than nutrition information (Storcksdieck Genannt Bonsmann and Wills 2012). The effectiveness of carbon labeling of food products has also been mixed. Some studies have reported positive results of carbon labeling schemes at pilot stage (e.g. Vanclay et al. 2011). However, an evaluation of carbon labeling for all food products by a large UK supermarket chain between 2008 and 2012 found that this had no impact on actual purchasing behaviour (Hornibrook et al. 2013). Other studies in developed countries have identified varying levels of support among consumers for carbon labeling of food products (Gadema and Oglethorpe 2011; Upham et al. 2011; Hartikainen et al. 2014). These studies note that consumers find labeling difficult to interpret, that consumers' purchasing decisions are mostly affected by other factors (e.g. price, quality), and that food brands may also be reluctant to disaffect some consumers by promoting carbon labeling. Several such studies have stressed the importance of industry initiatives to reduce the carbon footprint of food rather than relying on demand-side efforts.

Other forms of product labeling include those related to sustainability certification schemes. Market opportunities for certified sustainable products are growing in many industrialized countries along with growing awareness and demand for high quality or sustainably sourced products (Rueda and Lambin 2013). According to Potts et al. (2014), standard-compliant products account for a significant proportion of selected internationally traded commodities: 40% of global coffee production, 22% of cocoa, 15% of palm oil and 12% of tea production is standard-compliant. However, the majority of standard-compliant output in all these commodities is not sold as standard-compliant (ibid). This oversupply may reflect barriers to market access, and may be taken to indicate potential to meet future growth in demand for standard-compliant products as certified products gradually move towards mainstream markets. On the other hand, if price premiums are not obtained for standard-compliant products, incentives for producers to remain compliant may diminish over time, and oversupply may diminish the incentives for buyers to require compliance. Demand for certified products will continue to increase for some internationally traded commodities, but willingness to pay for 'sustainable' products is much more varied for other agri-food products. Willingness to pay and actual purchasing behaviour varies among social groups and between product types, and perceptions of food safety or product quality may outweigh the perceived importance of sustainability criteria (Loureiro and McCluskey 2000; Bernués et al. 2003; Krystallis and Chryssohoidis 2005; Janssen and Hamm 2012). In these supply chains, investment by lead firms and partnerships among value chain actors in improving environmental, social and economic outcomes may be more relevant than certification schemes. A further challenge for certification may come from the lack of evidence of the positive impacts of certification schemes. For example, a systematic review found limited reliable evidence that certification schemes have positive economic or environmental effects at producer level (Blackman and Rivera 2010). This finding reflects partly the limited number of peer-reviewed studies on these schemes, and highlights the need for more attention to evaluation in these schemes (Milder et al. 2015). In addition, some standards have been criticized for having weak sustainability criteria and for weak enforcement mechanisms (Laurence et al. 2010; Balch 2013; Colchester and Chao 2013).

2.2 Approaches to reducing food loss and waste in agri-food supply chains in developing countries[5]

Section 1.3 reviewed the general state of knowledge on food loss and waste in developing countries, noting that losses and waste mostly occur in the post-harvest handling and storage, processing and packaging and distribution stages. However, meat and dairy product losses in some developing regions are an exception. In developing regions (and in SSA in particular) livestock product losses mainly occur in animal production and may be attributed to animal mortality. Global data on animal mortality and its specific causes is sparse,[6] but is likely to vary between regions and countries depending on factors such as urbanization, changes in animal production systems and changing patterns of trade (FAO 2013; Perry et al. 2013). Where livestock intensification is a dominant process, increased attention to product quality, health, safety and traceability is often associated with increased demand for animal health services. Where production is dominated by smallholders who are weakly integrated into markets, animal health service provision typically remains weak. Reducing livestock mortality is a key component of supply-side GHG mitigation efforts (Gerber et al. 2013), but may also be supported by downstream value chain initiatives, such as commodity based trade (Thomson et al. 2013), or interventions in shorter value chains that link animal health and biosecurity measures to market access.

[5] This paper will not focus on industrialized countries, where food loss and waste is concentrated in the consumption phase. The focus of this paper instead is on losses in production and pre-consumption stages of supply chains. For additional information on industrialized countries and demand-side food waste, please refer to FAO 2011b.

[6] The World Organization for Animal Health (OIE) maintains a database of notifiable diseases. See http://www.oie.int/wahis_2/public/wahid.php/Wahidhome/Home

Livestock products aside, losses and waste of cereals, roots and tubers, and fruits and vegetables are significant in developing countries. These losses mainly occur in post-harvest handling and storage, processing and packaging and distribution stages. Approaches to addressing food loss and waste and in these pre-consumption stages include technology- and infrastructure-based approaches, value chain approaches and policy-based approaches. Each of these approaches is discussed in the sections that follow.

Technology and infrastructure approaches

Causes of food loss and waste vary significantly between commodity types and regions. In cereals, much of the losses in developing countries are attributed to inappropriate post-harvest handling, storage, processing (e.g. drying) and packaging, where they can become vulnerable to moisture and pests (Kimenju and De Groote 2010; IICA 2013). Facilities and infrastructure may be one contributing factor. For example, many smallholders in developing countries lack access to appropriate storage or drying facilities, although various technologies exist (IICA 2013; Affognon et al. 2015). Drying grains and cereals is a necessary post-harvest process in the agri-food supply chain. Many smallholder farmers do not have access to appropriate facilities and thus experience high losses during the drying phase, where often grains are exposed for lengthy periods of times in various structures including unroofed cribs, floors or terraces (Kiaya 2014). If grains become too dry they can become brittle and crack causing further losses, and if the grains are not dry enough, they will be susceptible to mould in storage which can lead to further losses (ibid). During this phase various losses occur often from pests including birds, mice and insects, which in turn also can leave droppings which will lead to further food losses and or food-safety concerns (Sharon et al. 2014). Solar dryers have also been identified as promising investments in developing countries to reduce post-harvest losses, especially for cereals/grains, nuts, coffee, beans and fruits (Vijayavenkataraman et al. 2012; Pirasteh et al. 2014).

For perishable fruit and vegetables, the large difference between losses in developed and developing countries has been attributed to the lack of cold storage facilities (Winkworth-Smith et al. 2014; Rais and Sheoran 2015). For example, in India only 10% of fruits and vegetables have access to cold storage, and losses are estimated to be between 25-30% in the post-harvest handling and storage, processing and packaging and distribution phases (Rais and Sheoran 2015). For fresh produce, packaging innovations can further reduce waste by ensuring product protection, ventilation and temperature control, through technologies such as multi-layer barrier packing, modified atmosphere packing, edible coatings, moisture absorbers and aseptic packaging, although these technologies are often not widely adopted in the developing world (Verghese et al. 2015).

In addition to physical facilities and infrastructure, adoption of improved techniques is relevant. One meta-analysis of studies on four crop types in SSA found that with appropriate interventions (e.g. crop variety selection, biological and botanical control measures, chemical treatments, improved handling and processing, as well as storage structures), quantitative losses could be reduced from about 21% to about 4% for maize, from 75% to 17% for mango, from 75% to 53% for cassava chips and from 42% to 26% for sweet potato (Affognon et al. 2015). However, a number of innovations reported in that study had not been commercially scaled for adoption.

Discrepancies in the adoption of various post-harvest technologies are linked to diverse factors such as climate, geography, access and cost of electricity, socio-economic context, political support, and the availability and quality of extension services (Kimenju and De Groote 2010; Kitinoja et al. 2011; Guillou and Matheron 2014). Common barriers that often prevent the dispersal of technologies to reduce post-harvest losses include (Kitinoja et al. 2011): inadequate marketing systems, inadequate transportation infrastructure, unavailability of needed materials, tools or equipment (or too costly), lack of information and awareness, and a lack of an enabling environment including government regulation and legislation. In particular, the technology needs to be suitable for the area in which it will be implemented. For instance, while cooling systems have been proven to expand the lifespan and quality of various perishable food products, they require large-scale investments, they are often energy intensive and are costly to maintain, may rely on refrigerants with a high impact on global warming, and may lead to food waste in other phases in the food chain, such as consumption (Garnett et al. 2015).

As a result, there is still substantial room for innovation to improve supply chain infrastructure and to reduce food loss and waste in developing countries. Despite several technologies and innovations having been developed, there are challenges in designing, testing, disseminating, evaluating and upscaling these technologies in different farming contexts (World Bank et al. 2011). Post-harvest technologies are now most often assessed and promoted within a value chain approach, in which constraints, incentives, intervention points and sustainable linkages can be better assessed. Text boxes 4-6 give examples of technologies and some of the opportunities and challenges associated with their adoption.

Text box 4. Metal silos to reduce post-harvest losses

There is a growing evidence base that shows the potential for metal silos to reduce post-harvest losses in developing countries (Kimenju and De Groote 2010; Tefera et al. 2011; Bokusheva et al. 2012; Gitonga et al. 2013). Grains and cereals tend to experience high losses process due to inappropriate storage that exposes them to pests (e.g. birds, insects), or micro-organisms (Tefera et al. 2011; Baoua et al. 2015). Post-harvest losses for grains or cereals during the storage phase are often within the range of 10-30% in developing countries, although this differs by commodity, region and common storage practices (Kimenju and De Groote 2010; FAO 2011b).

Metal silos are air-tight containers, usually consisting of an iron structure that is hermetically sealed. The structure prevents pest invasions since it is hermetically sealed, and since it is airtight insects and other pests cannot survive. Silos can be developed for different scales including at the farm-level, trader or association-level, or industrial storage – ranging from 100kg of storage to 3000 kg (Tefera et al. 2011). They have been commonly used in Central America, and in recent years they are being studied in other regions of the world, including SSA (Tefera et al. 2011; Bokusheva et al. 2012).

Studies have showed promising results in the effectiveness of metal silos to reduce post-harvest losses. In Central America, the Swiss Agency for Development and Cooperation spent over twenty years developing and distributing metal silos in El Salvador, Guatemala, Honduras and Nicaragua. The project showed that metal silos improved food security and post-harvest food losses in communities, and thus improved the well-being of households (SDC 2012; Bokusheva et al. 2012). A study in Kenya found that post-harvest food losses in the storage phase could be reduced from approximately 24% to 1.7-0.5% (Kimenju and De Groote 2010). Another study in Kenya found that farmers were able to save between 150-200kg of grain when using metal silos compared to typical practices (Gitonga et al. 2013). These savings are equivalent to USD 130, while additional benefits observed included reduced need for pesticides, and increased storage lengths (Gitonga et al. 2013). One main challenge to broader adoption is that smallholder farmers may be unable to make the initial investment in a silo. For example, in Kenya costs were around approximately USD 196 per 1.8 ton of storage (Gitonga et al. 2013). It may be necessary to develop programmes providing subsidies or credit to enable adoption. India, which also experiences losses in the range of 10-20% of cereals and grains, has explored the possibility within public-private partnerships (PPPs) to invest in improved grain silos to increase the national capacity and reduce post-harvest losses (Sharon et al. 2014). While studies have shown promising results with this technology, there is a need to develop an upscaling strategy based on comprehensive feasibility assessments to engage the private sector and ensure the appropriate dispersal and use of these beneficial technologies.

Text box 5. Developing cold chains to reduce food loss and waste in agri-food value chains

Cold chains are an important technology for reducing post-harvest losses of perishable products, especially in countries with warm climates. The segments of an integrated cool chain include (Kitinoja 2013): i) packing and cooling fresh food products, food processing, iii) cold storage, iv) distribution and v) marketing. An estimated 23% of perishable foodstuffs in developing countries are lost due to the lack of refrigeration – or over half of the total food loss in these countries (IIR 2009 in Kitinoja 2013). Adoption of cold chains is often still limited in many developing countries. The development of cool chains faces a number of challenges, including high-costs, and limited access to reliable and cheap electricity in rural regions. Kitinoja (2013) further emphasize the need to promote an integrated approach that not only promotes the use of sustainable cold chain technology, but also improves maintenance and associated services, infrastructure education, management skills, and the development of markets. It should also be noted that refrigerants are a source of GHG emissions and trade-offs may occur when refrigeration facilitate increased food waste during the consumption phase (Garnett et al. 2015).

Various technologies have been developed depending on the exact needs for refrigeration. For short-term storage at the farm level, Zero Energy Cooling Chambers (ZECC) have been developed for arid or semi-arid regions. ZECCs cost approximately USD 600, and can store 100 kg of fresh produce for 1 week (Barrett et al. 2013). They consist of a brick and sand evaporative cool chamber covered by a thatched shade structure to protect the ZECC from the sun. CoolBot™ controllers are another technology that has been adopted in some programs for improving cool chains, and can cool a small insulated room (~3m x 4m) to between 12-2°C (Barrett et al. 2013). These rooms reportedly cost around USD 7,000 and provide 1 ton of refrigeration capacity (3.5 kW) (Winrock 2009 in Kitinoja 2013). Although high, these costs are approximately only 10% of the cost of a commercial refrigeration unit.

Often cold chains may exist for exported products, and it has been suggested that these models serve as examples to expand cold chains into domestic markets (Kitinoja 2013). The private sector can invest in technologies, and extension services to improve the uptake of cold chains within their supply chains (Barrett et al. 2013). The government should invest in public infrastructure (electricity and roads), while also creating an enabling environment to encourage the uptake of these technologies and approaches.

Text box 6. Reducing post-harvest losses using improved packaging throughout the agri-food supply chain

With the handling and transportation of fruits and vegetables, high losses are often attributed to mechanical damage, which is often linked to poor quality packaging (Kitinoja et al. 2011; Kitinoja and AlHassan 2012; Verghese et al. 2015). For instance, in SSA and India packages for fruits and vegetables often are too big, too rough or too flimsy to adequately protect the produce from mechanical damage (Kitinoja and AlHassan 2012). Also, packaging often does not have an adequate amount of ventilation for perishable products, which can speed up the deterioration of these products (Kitinoja and AlHassan 2012; Verghese et al. 2015). This can affect food loss and waste during subsequent stages, including processing, handling, transport and distribution. The deterioration or complete loss of food due to inappropriate packaging can lead to substantial losses of food, and incomes throughout the entire value chain. For example, in Rwanda one study found that the percent of bananas discarded before wholesale include approximately 14.8% at the farm level, 35.1% at the wholesale level, and 30.1% at the retail/market level (Kitinoja and AlHassan 2012).

Improved packaging often includes simple, inexpensive improvements that can substantially reduce food loss. For example, in Ghana reducing the size of sacks used to transport cabbage reduced food loss from 30% to 10%, due to a reduction in mechanical damage (Kitinoja and Holben 2010). In India, unlined rough crates led to high losses of guava fruit, and thus liners were introduced into creates to reduce losses where market values per crate increased by 12.5% due to reduced damage (Kitinoja et al. 2010). Further advances in primary packaging include using multi-layer barrier packing, modified atmosphere packing, edible coatings, moisture absorbers and aseptic packaging (Verghese et al. 2015). Waste at the consumption stage can also be reduced by packaging innovations, such as clarifying best-before dates and providing information on best storage options, appropriate portion sizes and improved packaging design (e.g. resealable packaging) (Verghese et al. 2015).

Value chain approaches

Value chains consist of the set of actors (including public organizations as well as private firms) and the sequence of activities performed to bring a product from production to the consumer (Miller and Jones 2010). Value chain analysis is used to identify the actors and factors affecting constraints to efficiency, productivity and competitiveness in the value chain. Focusing on value chains, rather than on individual technologies, value chain approaches are increasingly used to promote commercial practices affecting food loss and waste.

Low levels of product commercialization and weak integration of smallholders in agri-food value chains is another common factor affecting waste and losses. The full range of value chain interventions may all be relevant to addressing this. Forms of horizontal integration (e.g. producer or marketing cooperatives) as well as vertical integration (e.g. formal supply contracts or supply chain quality management) can not only enable or incentivize on-farm productivity, but also provide support in reducing food losses through joint investments, improving supply-chain processes and providing extension services (Markelova et al. 2009; Affognon et al. 2015). Producer organizations and downstream firms may provide training and capacity building services, and producer organizations may also enable farmers to pool their resources for joint investments in technologies (e.g. grain silos). Producer organizations can play an important role in overseeing the supply chain and creating important linkages between actors and processes from production, collection, processing, distribution and retailing (Affognon et al. 2015). They can further support the implementation of innovations, such as improved packaging technologies or processes that reduce damage and loss of products in intermediary stages of the agri-food supply chain. The adoption of improved practices or technologies can result in higher quality products, which can increase product marketability and reduce quality-related economic losses.

Functioning supply chains require not only cooperation among supply chain actors (including farmers as well as between producers and other firms), but also rely on other supporting functions, such as transport networks, standards and regulation enforcement, and credit markets. Taking advantage of the opportunities to reduce food loss and waste in supply chains therefore requires support from a range of actors, including government, farmer and industry associations and the financial sector (Markelova et al. 2009). Text box 7 illustrates how interventions partnering with different value chain actors can address food loss and waste throughout the value chain.

Text box 7. Supporting value chain actors to reduce post-harvest losses in Rwanda

Rwanda's agricultural economy is based on smallholder farmers, most of whom have very small plots of land. Fragmentation in production increases the challenges of marketing, and many farmers lack capital and capacities for efficient harvesting, storage and marketing of agricultural surplus. Grain losses are estimated at 15% to 22%. The USAID-financed Post-Harvest Handling and Storage (PHHS) project supported a number of initiatives focusing on value chain interventions to reduce post-harvest losses.

One focus of the PHHS project was on supporting farmer cooperatives to improve market access for farmers. Financing the aggregation of crops was identified as a key constraint. The project facilitated linkages with financial institutions to relieve credit constraints through facilities to allow cooperatives to borrow against future orders from buyers, thus enabling finance of purchases from cooperative members. The project also worked with financial institutions to improve the suitability of their internal mechanisms for providing the financial product. These linkages were supported also by increased investment in storage facilities. The project worked with the country's largest grain buyer to co-invest in backward linkages with farmers and post-harvest processes. Investments were made in village aggregation centres, grain bulking centres and post-harvest equipment and techniques. Competitive grant tenders were used to select cost-effective proposals for investments in village aggregation centres and for innovation grants to support new business concepts to improve linkages in target value chains. The project's grants supported 104 storage existing or new centres and leveraged over USD1.6 million in new private sector investment.

Source: Van Dusen and Beyard n.d. (USAID)

Policy approaches

National governments can play key roles in addressing food loss and waste. The development of national strategies and action plans can raise awareness and create political momentum, while also proposing concrete targets and strategies to address the challenges associated with food loss and waste. A wide range of policy measures are relevant. Key roles for public policy in addressing food loss and waste in SSA include creation of an enabling environment and provision of public goods such as electricity and roads; integrating post-harvest losses into agricultural research and extension; providing direct support to net deficit grain producers in food insecure communities; and evaluating progress in addressing food loss and waste (World Bank et al. 2011). Text box 8 highlights some ways in which public policy supported the development of cold storage for potatoes in Bihar State, India. In developing countries with more developed agri-food sectors, the roles of public policy may include: raising awareness among agri-food supply chain stakeholders; developing guidelines, regulations and policies relating to food waste treatment and use (e.g. livestock feed), packaging, food hygiene/safety and product labeling; research, technology and infrastructure development (WRAP 2015).

Financing the investments required is also a critical area that may require policy innovation. Opportunities to reduce post-harvest losses provide significant opportunities for private investment. For example, the 2013 Food Security Bill in India implied the need for a significant growth in grain warehousing facilities (Rabobank 2013). Rabobank identified that many of these investments would be more suited to larger investors who are better able to cope with seasonal fluctuations in storage capacity and prices, and long project gestation periods. Many technologies suited to adoption by farmers will also be promoted by the private sector, which will require access to suitable financing products. Given that most agri-food supply chain processes involve the private sector, public-private partnerships (PPPs) are a very relevant approach to creating an enabling environment and piloting technologies for upscaling interventions. PPPs can play a crucial role in catalysing investments and overcoming investment risks and barriers (e.g. technology, policy, capital). PPPs can use public finance to reduce private sector risk and incentivize the private sector to become engaged in reducing food loss and waste throughout agri-food supply chains, and to contribute their expertise on the ground. This can include support to developing innovative scalable approaches to reduce post-harvest losses.

Text box 8. The roles of policy and investment in cold storage in transforming potato markets in Bihar, India

Potato is a major vegetable crop in India, including in Bihar, one of the poorest states. Storage is a major challenge, as the harvest is followed by a season of high temperatures. Most potatoes are produced by smallholders and sold in a trade estimated to be worth USD0.4 billion. Between 2000 and 2009, the number of cold storages for potatoes increased by 64%, with an even greater increase in storage capacity over this period.

The expansion of storage facilities led to an increase in storage of table potatoes in addition to seed potatoes, and increasing use of storage facilities both by farmers and traders. Farmers using cold storages were able to receive significantly higher prices through off-season sales, which reflected the ability of farmers using cold storages to obtain a higher proportion of the total value of final sales than farmers selling fresh potatoes shortly after harvest. Wastage of potatoes also decreased.

Factors that enabled the expansion of cold storage in Bihar included regulatory reform and improvements in provision of public goods and governance, public subsidies and technological advances that reduced the cost of storage. Specific factors identified included: regulatory reform that removed licensing requirements for cold storage; significant expansion of road networks that facilitate and reduce the costs of transportation; and improvements in the security environment within the state. Cold storage investments (about USD1 million per facility) also benefited from subsidies from the National Horticultural Board, state government and the State Industrial Promotion Board. The availability of high-speed compressors in the 2000's also significantly reduced the costs of cold storage operations, while research and extension led to promotion of potato varieties more suited to storage.

Source: Minten et al. 2010

Text box 9. Supporting innovation in countries with rapidly transforming agri-food sectors

In emerging countries, agri-food supply chains are dynamic, and a range of new challenges are posed throughout supply chains. Public agencies can play key roles in supporting innovation to address these emerging challenges.

In South Africa, the Post-Harvest Innovation Programme is a public-private partnership between the Department of Science and technology and the Fresh Produce Exporter's Forum to support research, development and innovation to enhance the global competitiveness of the country's horticultural industries. The programme partners with industry associations to identify and fund research projects that address specific post-harvest challenges. Priority technology gaps have been identified in a range of areas including container and cold storage technology, packaging solutions, resource efficiency and sustainability, technology transfer, logistics, post-harvest physiology, disease and insect control and temperature and humidity control.

In China, several ministries support both basic and applied research on the agri-food sector. In recent years, research, development and innovation in the development of supporting functions for ensuring food safety in commercial supply chains have been particular areas of focus. National plans have prioritized key food processing enterprise technologies (e.g. equipment for rapid testing of nutrition, hygiene and safety indicators, and systems to support enterprise process inspection), domestic production of related equipment and supply chain monitoring, control and traceability systems. A National Plan for Food Safety Research & Development was also developed that prioritizes support for basic food science, food engineering technologies, biotechnology and product innovation, contaminant monitoring, deep processing, quality and safety process intervention and control, and food product logistics. Research and development grants are available to research institutes and companies, and subsidy grants are available to co-fund adoption of improved practices in agri-food supply chains. A higher objective of these programs is to meet the increasingly diverse demands of citizens for quality and safe food products, while improving resource efficiency in the agri-food sector.

While these types of public funding often support innovation in highly commercialized agri-food product value chains, similar approaches can and have been applied to traditional food crops, such as cassava, which has recently been targeted with a USD1 million innovation challenge.[7]

Sources: People´s Republic of China (2011); Ministry of Science and Technology of the PR China (2012); Post-Harvest Innovation Programme (2015).

[7] https://www.rockefellerfoundation.org/cassavachallenge/

3. Summary and discussion

3.1 Summary of findings

This report has been motivated by the recent studies suggesting not only that supply-side GHG mitigation options in agriculture will be insufficient to prevent further increases in absolute levels of GHG emissions from the AFOLU sector, but that demand-side measures, such as dietary change and reductions in food loss and waste, may have a larger technical mitigation potential than supply-side measures (e.g. Bajželj et al. 2014; Smith et al. 2014; Smith et al. 2013b). GHG emissions from livestock are one aspect of analysis that has received significant attention. The argument that AFOLU emissions can only decrease if dietary patterns change (i.e. less meat is consumed) and if food loss and waste are reduced has gained rapid circulation in policy circles. This highlights the timelines of an assessment of the extent to which demand-side mitigation policies and measures are readily available for deployment. A qualitative summary of this report's findings is illustrated in Table 2, with further description of the key findings in Table 3.

Options to promote dietary change that were reviewed included 'hard measures' such as food subsidies and taxes, and 'soft' measures such as health promotion and education, product labeling and certification standards. There is some evidence that subsidies to 'healthy' foods can increase their consumption. Evidence on taxation of 'unhealthy' foods is much more mixed, has rarely focused on animal source products (especially meat), and has almost exclusively focused on developed countries. Available evidence points to challenges related to substitution effects that are largely unknown, the risk of regressive distributional effects, and likely political difficulties in promoting taxation policies, especially for taxes on livestock products. Overall, there is insufficient understanding of the effects of taxation policies to enable them to be recommended with confidence (Cornelsen et al. 2014).

Health promotion initiatives (e.g. promoting consumption of fruit and vegetable or targeting diet and behaviour related to chronic disease risks) have been found to have mostly positive but small or insignificant effects on consumption of targeted foods or on targeted health outcomes, but may have more significant impacts where 'at risk' populations are targeted.

Table 2. Qualitative summary of available supporting and limiting evidence for measures to promote dietary change and reduce food loss and waste

	Availability and strength of evidence for the measure's effectiveness	Availability and strength of evidence against the measure's effectiveness
Dietary change		
Subsidies to ´healthy´ foods	* *	*
Taxes on animal-source foods	*	* * *
Public health promotion of ´healthy´ foods	*	* *
Public health promotion to reduce disease risks	*	* *
Restrictions on advertising		*
Product labeling		*
Sustainability certification		*
Reducing food loss and waste		
Technical approaches	* *	* *
Value chain approaches	*	*
Policy approaches	*	*

Note: one star in the 'supporting evidence' column indicates presence of evidence; one star in the 'limitations in evidence' column indicates either lack of evidence or evidence to suggest limited effectiveness.

Available evidence is insufficient to quantify the effects of health promotion initiatives on dietary composition and thus on diet-related GHG emissions. Evidence on the effectiveness of product labeling on consumer purchase decisions is also limited. It is known, however, that the effectiveness of these 'soft' measures varies among social groups and that consumer decisions are affected by a number of factors, limiting the effectiveness of information provision as a measure to promote dietary change.

With regard to reducing food loss and waste, a range of technical, technological and infrastructure options have been documented as effective in significantly reducing post-harvest losses. However, adoption rates are often low. While many projects have led to improvements in some aspect of post-harvest systems, few have achieved larger impacts because of a lack of commercial incentive for investment and scaling-up (World Bank et al. 2011). Post-harvest technology innovation is now most often promoted in a value chain approach in which constraints, incentives and intervention points can be better assessed, and sustainable linkages for commercialization of solutions developed. There is increasing awareness of the relevance of policies for addressing food loss and waste, supported by the inclusion of the topic in Sustainable Development Goal 12, which aims to *´ensure sustainable consumption and production patterns´*, and by the efforts of an FAO-led initiative to address food loss and waste. (UN 2015; FAO 2016)

3.2 Key implications

Reflecting on the findings of this review, we discuss four key implications of the debate on supply- and demand-side agricultural GHG mitigation efforts: (1) evidence on the technical, social, economic and political feasibility of demand-side measures; (2) the importance of linking demand-side measures with stakeholder concerns beyond GHG-related issues; (3) the relevance of value-chain approaches for identifying key leverage points; and 4) the importance of measures to support private sector investment.

3.2.1 The realistic potential of demand-side measures will be considerably smaller than available estimates of technical GHG mitigation potential

Reduction in consumption of animal products has been one focus of the literature on demand-side agricultural GHG mitigation measures. With the exception of studies of the effects of taxation, most studies of the technical mitigation potential of demand-side measures simulate scenarios based on alternative diets, but without specifying how dietary change can be achieved. It is relevant to note that many of these modeling results are based on quite strong assumptions, such as major reductions in meat consumption or total elimination of meat or animal product consumption (e.g. Stehfest et al. 2009, Popp et al. 2010), or less extreme but still strong assumptions such as replacement of ruminant meat with pork or chicken (Hoolohan et al. 2013). Analysis of decades of health promotion initiatives shows some evidence that various measures can promote dietary change, but reviews generally report small average changes achieved in the longer term (Miller et al. 1997; Pennant et al. 2010; Rekhy and McConchie 2014). There is some evidence that effects are more significant when particular groups in a population, such as school children, women and groups at risk of chronic disease, are targeted (Thomson and Ravia 2011; Fjeldsoe et al. 2011). Subsidy and taxation measures may also affect some consumers' purchasing decisions, but substitution effects are likely to reduce the size of these effects on diet-related GHG emissions. Several studies have analysed the potential effects of taxes on meat in developed countries (e.g. Wirsenius et al. 2011; Dhyr Edjabou and Smed 2013; Säll and Gren 2015). Despite the wealth of evidence that livestock are a contributor to agricultural GHG emissions, environmental pollution and inefficient use of resources and chronic disease burdens, the potential effects of meat taxes in developed countries are insufficiently understood to recommend them as a policy measure (Cornelsen et al. 2014). There has been very little related research in developing countries, where most of the future increase in livestock emissions is projected to occur. Wellesley et al. (2015) report the results of an online survey and a series of focus group discussions in developed countries as well as Brazil and China. Consumer awareness of the links between animal product consumption and climate change is low, and awareness alone will be insufficient to promote behavioural change (ibid). This suggests that in developing countries, where significant proportions of rural people are often livestock keepers, livestock is an important driver of agricultural growth, and livestock make important contributions to nutrition and food security, it is unlikely that calls for 'hard' policy measures to increase the price of livestock products would gain traction in policy circles. Overall, the available evidence (mostly from developed countries) and consideration of the politics of food and agricultural policies in developing countries suggests that economic and non-economic factors affecting consumers' decisions will mean that the feasible mitigation potential of policies and measures to promote dietary change is much more limited than current estimates suggest.[8] Data potentially relevant to a revised global estimate is being generated by the Global Nutrition and Policy Consortium.[9]

[8] For example, if one assumes that meat taxes are only applicable in developed countries, dividing the per capita emission reductions due to a EUR 60/tCO_2 tax modelled by Wirsenius et al. (2011) by the population of the EU27 and multiplying by the population of more developed countries (UN 2012) provides an estimated emission reduction of 3100 MtCO_2e over a 40 year period to 2050, which is ca. 50% of the global mitigation potential of dietary change estimated by Bajželj et al. (2014).

[9] http://www.globaldietarydatabase.org/

Table 3. Qualitative summary of evidence on the strengths and weaknesses of potential demand-side measures for mitigation of GHG emissions

Approach	Strengths	Limitations
Dietary change		
Subsidies to 'healthy' foods	Consistent evidence that subsidies increase consumption of targeted food types.	Effects on overall consumption (and thus GHG footprint) unclear; Possible 'rebound effects' unclear.
Taxes on 'unhealthy' foods	Modeled evidence potential to change consumption of high GHG footprint products; Some evidence of dietary change among specific subgroups for targeted foods.	Very little empirical evidence on meat taxes or on taxes in developing countries; Effects on overall diets, on low income groups and on the agri-food sector unclear, including possible 'rebound effects'; Political barriers likely to be high.
Public health promotion of 'healthy' foods	More successful when 'at risk' groups targeted; Likely to have public & policy makers' support.	Evidence suggests variable and small long-term changes in consumption.
Public health promotion to reduce disease risks	Some evidence of effective school-based initiatives, including in developing countries; Likely to have public & policy makers' support.	Evidence suggests positive but small health benefits when general population targeted; Specific evidence on dietary change due to interventions insufficient to estimate GHG benefits.
Restrictions on advertising	Likely to have strong public support.	Limited evidence of reductions in exposure to advertising or on actual consumption.
Product labeling		Other factors likely to dominate purchase decisions; Little evidence of carbon labeling impact on purchasing decisions; Limited demand from consumers or retailers.
Sustainability certification	Growth in internationally traded commodities.	No evidence relating to meat.
Food loss & waste		
Technology-based approaches	Numerous potential applications; Likely to have strong private sector involvement.	Empirical evidence of effective reductions in loss & waste; Initial investment costs can be high for smallholders; Commercialization of technical options often limited.
Value chain approaches	Numerous potential applications and measures; Likely synergies with profit-making incentives of value chain actors.	Quantitative data on effective reductions in loss & waste limited; May require complex collaboration among value chain actors as well as government, civil society, finance sector.
Policy approaches	Numerous potential measures; Can play key roles in mobilizing other agri-food chain actors; Likely potential to mobilize private sector investment.	May require complex collaboration among agri-food sector stakeholders, including various government ministries, civil society, private sector, finance sector.

Existing global estimates of the mitigation potential of reductions in food loss and waste (e.g. Bajželj et al. 2014) are based on models that assume existing loss and waste is reduced by 50%, which has been adopted as a target in relation to Sustainable Development Goal 12.[10] Reductions in supply chain losses and waste can support food security, resource use efficiency and enterprise profitability objectives, and should therefore be politically acceptable among a range of stakeholders in most countries. Evidence is available showing that specific technical and infrastructural interventions can potentially achieve loss reductions of 50% or more for some interventions and product types (Affognon et al. 2015). However, existing experience suggests that the commercial deployment of many technical innovations has been limited (World Bank et al. 2011). The rate of deployment of loss and waste reducing measures through food supply chains across the world will thus also be a key determinant of the feasible mitigation potential of loss and waste reducing measures. This will require not only technical and infrastructural interventions, but also value chain innovations to improve supply chain efficiencies, and supporting policy measures (ibid). Text box 10 highlights key areas where more research is required to improve estimates of demand-side mitigation potential.

Text box 10. Future areas for research to quantify demand-side GHG mitigation potential

Dietary change:

- Quantification of GHG mitigation scenarios targeting sub-populations at risk of diet-related chronic disease;
- Better availability of information on the effectiveness of approaches to promoting dietary change in developing countries;
- Research on food substitution effects, distributional effects, and supply-side effects of measures to restrict animal product consumption;
- Quantification of dietary change and GHG footprint due to health promotion measures.

Food loss and waste:

- Improved data on existing food losses, especially for food types with high GHG footprints (i.e. cereals, vegetables, animal products);
- Improved data on the effectiveness of loss and waste reduction measures;
- Quantification of GHG mitigation potential of reducing animal morbidity and mortality.

3.2.2 Building on synergies and linkages within other policy domains

The preceding somewhat pessimistic prognosis is balanced by recognition that there are potential synergies between demand-side GHG mitigation in the agri-food sector and other policy concerns. Non-GHG concerns have been significant in motivating national governments to develop supply-side agricultural GHG mitigation policies and programs (Wilkes et al. 2013). This report has highlighted that while livestock GHG emissions are a significant concern from a GHG mitigation perspective, livestock may be just one among many concerns from other perspectives.

For example, the health impacts of dietary and lifestyle change in both developed and developing countries are also based on concerns with increased or decreased intake of other food types (e.g. increased intake of high fat, sugar and salt foods and edible oils, reductions in legume and whole grain consumption) and decreased physical activity associated with urbanization and socio-economic deprivation (Popkin et al. 2012; Popkin 2015). The economic costs of chronic diseases such as cardiovascular disease, diabetes and risk factors such as obesity include not only direct medical treatment costs but also the costs of reduced returns to education, decreased incomes and increased early retirement (Yach et al. 2006).[11] The role of livestock product consumption and links with its both health environmental impacts is being increasingly recognized among public health researchers (e.g. McMichael et al. 2007). At the same time, many developing countries have begun to develop policies to address non-communicable diseases (Thow et al. 2014a and 2014b), although they often face numerous challenges (Ali et al. 2013; Thow et al. 2014b). The context for policy-setting is highly diverse between countries (Miranda et al. 2008; Yamada et al. 2013), as are the diet-related chronic disease burdens, the relative roles of livestock and other food types in diets, and the contributions of livestock production to agricultural and economic development. For social groups with high levels of meat consumption and where this dietary pattern has been identified as a health risk factor, the hypothesis that there is potential to promote measures to reduce meat consumption among at risk groups seems to be a reasonable one. However, concern with meat consumption should be balanced and integrated with other dietary and lifestyle concerns, including under-nutrition in some countries.[12] Where the

[10] http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/goal-12.html

[11] Estimates from the 1990s and early 2000s produced using different methodologies suggest that the costs of obesity may range from 0.2-2.1% of GDP, and of diabetes from 0.5-3.8% of GDP (Yach et al. 2006).

[12] For example, studies in China have characterized different dietary patterns among the population (Zhang et al. 2013, Yu et al. 2015), and identified young, inactive, high income earners who also smoke and drink as higher consumers of red meat and at risk of overweight (Wang et al. 2013;)

policy-related entry points for promotion of dietary change lie, and the options for policy development and implementation will vary between specific contexts (Text box 11). Targeting groups at risk of dietary health impacts would imply a much lower GHG mitigation potential for dietary change interventions than assumed in existing assessments. Nevertheless, this population is unfortunately growing rapidly, with already more than 2.1 billion adults and children overweight or obese (Ng et al. 2014), and studies projecting diabetes prevalence to expand from 382 million people to 592 million people in 2035 (Popkin 2015).

Estimates from FAO suggest that, globally, cereals, vegetables and meat account for more than 70% of the carbon footprint of food loss and waste (FAO 2015b). That study estimated that, by region, the largest GHG mitigation potentials are in Industrialized Asia (i.e. China and Japan, >700 $MtCO_2e$), followed by South and Southeast Asia (>400 $MtCO_2e$) and Latin America (ca. 200 $MtCO_2e$), with the smallest mitigation potential in SSA (ca. 100 $MtCO_2e$). The study assumed a scenario in which developing countries would reduce losses in production and processing by 15%, in post-harvest handling and storage by 54%, and distribution and consumption by 50%. Hence, large mitigation potentials are estimated for regions with large consumer populations.

There are a number of policy domains to which GHG mitigation through reducing loss and waste can be linked. In food deficit regions, reduced losses and waste of cereals and other staple crops can contribute to food security. Grain harvesting and storage technologies have been identified as priorities for SSA (World Bank et al. 2011). Infrastructure can also reduce post-harvest losses, while providing a range of other benefits to rural and urban economies (Rosegrant et al. 2015). A significant proportion of animal product losses (and their carbon footprint) in SSA are estimated to arise in production, mainly due to animal mortality. Improving animal health and animal feed are already core objectives of veterinary and livestock development policies in many countries. Concern with human-animal zoonosis, and international food safety standards have brought animal and human health increasingly together (Kamani et al. 2015). Reducing mortality and improving biosecurity may have strong synergies with supply-side efforts to increase livestock productivity, and with livestock sector, agricultural development, trade and health policy objectives. However, multi-sectoral coordination, logistical and financial resources, and the availability of qualified public and private veterinarians are common challenges in developing policies and delivering animal health services (Benet et al. 2006; Okello et al. 2014). Where agriculture is undergoing market-led intensification, reducing loss and waste in agri-food supply chains and quality improvements in agri-food productions can link with agricultural commercialization, farmers' income generation and food quality and safety agendas (Hodges et al. 2011). Agri-food product supply chains are diverse, with inter-household and inter-regional variation in the relative importance of different supply chains, the existence of multiple actors at each stage of the supply chain, and the need to link food loss and waste reduction with supply chain actors' incentives. This suggests that a bottom-up approach to priority setting and implementation, building towards national priorities may be a more appropriate approach than targeting resources to globally established priorities (Bond et al. 2013). Text box 12 illustrates how a national program can accommodate, respond to and support diverse initiatives. Text box 13 highlights future areas where further research can help identify supportive contexts for developing policy approaches to demand-side GHG mitigation measures.

Text box 11. Characteristics of livestock and health domains in CCAFS focal countries

The Climate Change and Food Security Program of the CGIAR (CCAFS) focuses on research in 21 countries in five regions: East Africa, West Africa, Latin America, Southeast Asia and South Asia. Appendix 1 presents summary data on agriculture and livestock production, health indicators and the development of non-communicable disease policies in each country. On the one hand, the data illustrates the diversity of contexts. For example, livestock contributes on average 30% of agricultural GDP, but contributes less than 20% in 4 countries and more than 40% in 6 countries. Health indicators also vary significantly. For example, average rates of obesity in 2008 were about 8%, but 6 countries (all in Latin America) had rates in excess of 10%. Seven out of the 21 countries have already developed policies to discourage consumption of 'unhealthy' foods or encourage consumption of 'healthy' foods.

The data may also provide a preliminary indication of 'hotspots' and countries where the nexus of meat consumption, health outcomes and GHG emissions may be relevant to stakeholders. Latin America stands out as a region where livestock contribute the largest proportion of total agricultural GHG emissions (excluding land use emissions), that has the highest per capita animal product availability and by far the highest rates of obesity. Rates of mortality due to diet-related diseases are also high (28%). In the African countries, per capita animal product availability and rates of disease and mortality are mostly still relatively low. Simple correlation analysis shows that, unsurprisingly, the contribution of livestock to agricultural GDP is correlated with per capita meat availability, but also with rates of obesity, while per capita meat availability is correlated with both rates of obesity and mortality from diet-related diseases. The existing status of health policy development shows that among the East and West African countries, only Ghana has developed related policies. In Latin America multi-sectoral policies have been developed in Colombia and Guatemala, while most South and Southeast Asian countries have developed some form of policy addressing dietary intake, but the contribution of livestock to agricultural emissions is lower in these countries than in most countries in Africa or the Americas.

Text box 12. The Waste and Resources Action Programme (UK)

The Waste and Resources Action Programme (WRAP)[13] is a non-governmental organization in the UK that works to bring together multiple stakeholders and promote change in behaviour. Food waste reduction is one of its focal areas. Its members include a large number of agri-food business, institutional food providers (e.g. school and hospital caterers), local governments and community groups. WRAP engages with national and local governments, industry bodies, companies, institutional and individual consumers in a number of ways.

Firstly, it has focused on conducting and translating research and evidence focusing on the extent and causes of food waste, and the barriers to addressing it. For example, it produced groundbreaking reports on food waste and food GHG footprints in the UK, which played a significant role in raising awareness of the issues among companies, government, the media and the general public. It has also published evaluations of innovative actions and its research has helped raise awareness of the business case for solutions to resource use issues. Second, it has brokered voluntary agreements involving government, companies and community groups to commit to action towards common targets and sharing of experience. For example, the Courtauld Commitment 2025 is a voluntary agreement aimed at improving resource efficiency and reducing waste within the UK grocery sector. In the framework of this agreement, numerous companies from producers through to retailers have undertaken a variety of measures to improve resource use efficiency and reduce GHG emissions and waste in their own operations and their supply chains. Examples of actions include improved packaging design, energy efficiency measures, and reduction in food waste throughout supply chains. WRAP also provides information, tools and practical advice to support practice change by business and consumers. Third, it has initiated and supported consumer campaigns, in collaboration with local governments, companies and community groups. For example, working with city councils, its media campaigns have been shown to have a significant effect in reducing food waste by households. Fourthly, WRAP also develops and implements grant and loan finance programs to support action in its focal areas.

Source: WRAP (2016)

[13] http://www.wrap.org.uk/

Text box 13. Future areas for research to identify supportive contexts for developing policy approaches to demand-side GHG mitigation measures

Dietary change:

- Mapping of countries where reduced livestock product consumption has synergies with public policies in other domains (e.g. health, environment);
- Better understanding of how non-communicable disease policies are made, who influences the policy formulation process, and linkages with agriculture and environmental policy processes;
- Indicators for assessing multiple dimensions of sustainability of diets.

Food loss and waste:

- Bottom-up identification of loss and waste reduction priorities and commercially viable interventions in product value chains with high GHG footprints;
- Analysis of existing policies and policy barriers in relation to different stages of value chains with high GHG footprint;
- Identification of synergies between loss and waste reduction measures with other policy domains (e.g. animal health, food security, feed hygiene and safety, trade).

3.2.3 The relevance of value chain approaches to linking supply-side and demand-side measures

Recent attention to the demand-side agricultural GHG mitigation highlights that points of intervention to achieve environmental, social and economic benefits in the agri-food sector may lie throughout agri-food value chains, from producers through to processors, retailers and consumers. Although relatively more food loss and waste in developing countries occurs in production than in developed countries, losses and waste in the post-production phases still account for the majority of loss and waste of many product types in developing regions (Figure 4; FAO 2011b; Lee et al. 2012). Quality and food safety issues that affect marketability and profitability for producers as well as health outcomes for consumers are also affected by processes throughout the supply chain (Memedovic and Shepherd 2009). Value chain approaches are widely used (particularly by public and private agencies involved in development cooperation) to understand how products are produced and supplied to consumers, to identify constraints on the quantity, value and profitability of supply, and to identify how value chain actors and other actors in the wider environment can collaborate in overcoming these constraints.

Value chains for different commodities and at different stages of development have different structures, which provide different incentives for value chain actors and different opportunities for intervention. Lee et al. (2012) distinguish, based on the degree of fragmentation or concentration among producers and retailers, among agri-food value chains that are dominated by traditional markets, that are buyer-driven, that are producer-driven and that are oligopolies (Figure 6). Examples of producer-driven value chains include the many branded, processed food products produced in developing countries mainly for export (e.g. canned vegetables or fruit), where large companies procure from farmers or from their own plantations, and sell their branded product to a large number of retailers. Examples of buyer-driven value chains include those where large retailers (e.g. supermarkets, coffee retailers) have significant influence over value chain processes. Oligopolies are value chains with few buyers and sellers who are mutually interdependent. For example, where state-run companies have a national monopoly on purchase and export of beef, and sales are regularly made to a small number of firms in developed country markets. While the analysis of Lee et al. (2012) focuses on the implications of value chain structure for incentives to implement food and agri-food standards, the distinction appears also relevant to analysis of opportunities to address both supply- and demand-side GHG mitigation options, in particular food loss and waste. Concentration among producers and manufacturers suggests higher feasibility to promote initiatives addressing production and issues in the upstream of value chains, while concentration among retailers (e.g. buyer-driven value chains, oligopolies) suggests higher feasibility to drive initiatives throughout the value chain (including engaging with consumers) by engaging with retailers.

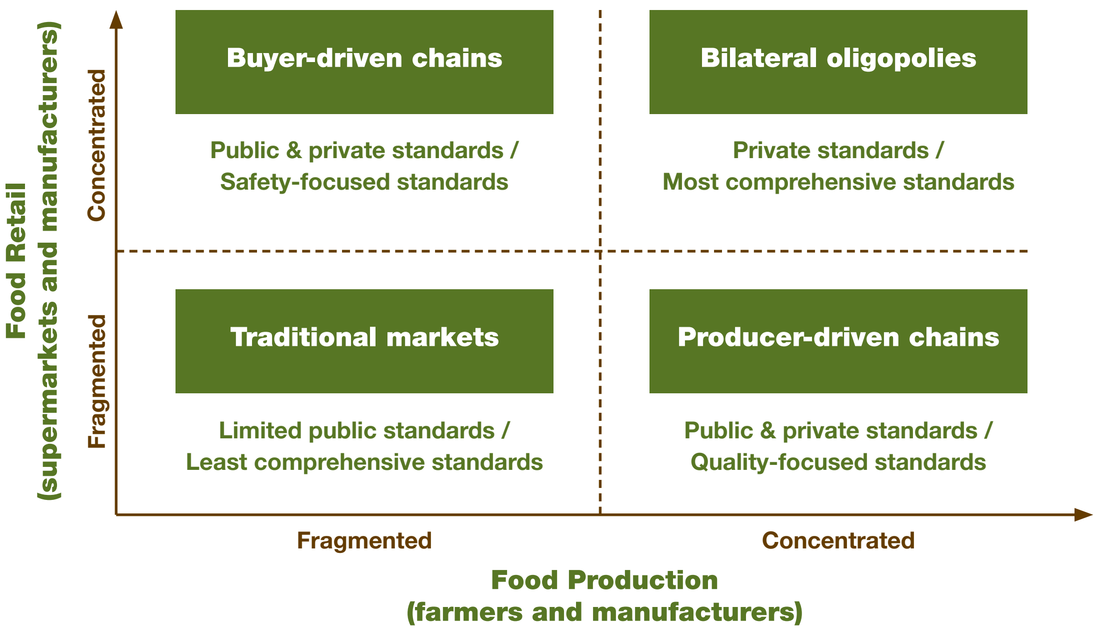


Figure 6. Stylized characterization of agri-food value chain structures. *Source: Adapted from Lee et al. (2012).*

In the case of buyer-driven value chains, because these value chains have stronger vertical integration, lead enterprises in the value chain are better placed to provide upstream actors with incentives and capacity support. They may also be well placed to engage consumers in related issues. Studies of the engagement of supermarket retailers with their supply chains on GHG mitigation suggest that a combination of external factors and a strong internal business case are required to sustain corporate engagement with their supply chains on the issue (Gouldson and Sullivan 2014). In the case of supermarkets in the UK, supportive external factors have included rising customer and media concern with climate change, government regulation on GHG reporting, and rising energy prices. Internal factors included target-setting processes and a strong financial business case for energy efficiency and GHG reducing measures.

In value chains where producers and manufacturers are more highly concentrated, some lead firms are also responding to the combination of external (e.g. regulatory environment, reputational risks) and internal factors (e.g. the business case) and implementing voluntary initiatives to address GHG emissions in their own operations and in their supply chains. Analysis by the Carbon Disclosure Project (CDP) suggests that global agri-food sector companies that engage with their supply chains, customers or partners on GHG emissions are significantly more likely to see a financial return on those efforts (CDP 2015). Many of the corporate signatories to the international declarations (e.g. New York Declaration on Forests) and members of international platforms (e.g. Save Food,[14] Global Alliance on Climate Smart Agriculture[15]), are implementing initiatives within their own supply chains or cooperating in pre-competitive initiatives involving several companies.[16] For example, the members of the Low Carbon Technology Partnership initiative (LCTPi) on climate-smart agriculture, recently launched by the World Business Council for Sustainable Development (WBCSD), are aiming to make 50% more food available, while reducing emissions by 50% by 2030.[17] Common approaches through which these companies engage with their supply chains include sharing knowledge, making procurement requirements, contributing financially and providing operational support (CDP 2015). While these examples highlight the relevance of promoting demand-side mitigation measures through companies with international operations or in export-oriented supply chains, specific supply chains in many developing countries are dominated by small numbers of manufacturers or retailers, and country contexts may also be supportive of action on GHG emissions as well as food loss and waste.[18] Animal product supply chains in developing countries may also share these characteristics, for example where formal sector milk processing is dominated by a small number of firms, or where meat production targets markets with food hygiene and safety standards, such as developed country export markets.

While value chains with concentration among producers, manufacturers or retailers may offer the greatest leverage for addressing food loss and waste, the majority of agri-food products in developing countries flows through traditional or modernizing supply chains, which are highly fragmented at both producer and retailer ends. In these supply chains, the transaction costs of working through the supply chain may be high, as illustrated by the difficulty of enforcing food safety standards in such supply chains (e.g. Huang et al. 2008). Value chain analysis has been found useful not only in identifying hotspots of food loss and waste in the value chain and in improving understanding of constraints and incentives faced by different value chain actors, but also in promoting collaboration among value chain actors in implementing solutions (World Bank et al. 2011). Increasingly, post-harvest technology innovation is supported through value chain approaches that support engagement of the private sector in providing solutions to value chain constraints. Considering the significant financial investments that are likely to be required to innovate, develop and commercially deploy related technologies and processes, how to structure economically feasible and inclusive investments for the private sector to effectively address post-harvest losses is likely to be a key future issue that has been little studied to date. Key areas where further research can support value chain collaboration on demand-side mitigation are highlighted in Text box 14.

3.2.4 Enabling private sector investment

Engagement of the private sector will be essential to enable demand-side measures to reach transformational scale. Promoting dietary change at the population level or among specific sub-groups may offer expanded or new business opportunities to part of the private sector, but there are also likely to be losses and trade-offs for some agri-food supply chain actors. These effects are currently little understood. For example, taxes on specific food categories have been found to raise companies' administrative costs, may affect profitability, employment and productivity, but may also stimulate investment in innovation (ECORYS 2014). Major

[14] http://www.fao.org/save-food/partners/en/

[15] http://www.fao.org/gacsa/members/en/

[16] E.g. http://www.coffeeandclimate.org/, http://www.bieroundtable.com/#!energy--climate/c1y5j

[17] http://www.wbcsd.org/agri-business-leaders-get-climate-smart-at-cop21.aspx

[18] E.g. http://www.reuters.com/article/carbon-agriculture-brazil-idUSL6N0OF3GK20140529

changes in demand in developed countries can have significant effects on welfare in exporting countries.[19] Reductions of food loss and waste in developed countries may also have adverse impacts on prices, income and welfare in developing countries (FAO and LEI Wageningen 2015). However, the positive opportunities for private investment in reducing food loss and waste are much clearer. Perception by the private sector of the availability of these opportunities is most likely affected by both external and internal factors, which are explored below. Text box 15 highlights key areas where research can help enable private sector investment in demand-side mitigation.

Physical infrastructure
Poor infrastructure is a significant factor contributing to higher post-harvest losses (Rosegrant et al. 2015). Increasing access to electricity, paved roads and railways can all support lower losses, and can have other benefits, such as lower food prices (benefiting consumers), higher food availability, and improved food security. An estimated USD415 billion of infrastructure investment would be required to reduce post-harvest losses in developing countries by 5%, mostly in Asia. Investment requirements in Africa are estimated at about USD75 billion (ibid). Governments have a key role in planning, mobilizing and making investments in infrastructure, but need also to mobilize private investment. Administrative capacities for managing public-private partnerships, supportive and stable policy environments and stronger regulatory roles for government, as well as financial innovations to manage investor risk will be required (ADB 2012; Collier 2014). Explicitly incorporating waste minimization in planning for transport and storage infrastructure would also be of benefit (WRAP 2015).

Public-private collaboration
Political commitment from higher levels of government can provide important signals, but ways are needed to translate political will into appropriate action. Multi-stakeholder platforms to enable and encourage collaboration (see e.g. Text box 12) can play important roles in building common understanding, generating an evidence base for identifying technologies and investment opportunities, and deliberating barriers that can be addressed by policies. At international level, initiatives such as SAVE FOOD, coordinated by FAO, are supporting actions involving national governments and other stakeholders at regional level.[20] These initiatives, and other related initiatives, such as public-private dialogues on climate-smart agriculture, are at an initial stage, and first results are just emerging. An analysis of successful public-private dialogues for agribusiness support would help to accelerate enabling support for public-private platforms to collaborate on addressing food loss and waste.

Text box 14. Key areas for research to support value-chain actors in collaborating on demand-side GHG mitigation measures

Food loss and waste:

- Better understanding of the business case for investment in loss and waste reduction in value chains with high GHG footprint, e.g. estimation of internal rates of return to interventions;
- Better understanding of value chain actors' incentives to engage on loss and waste reduction in their own operations and in partnership with other actors in value chains with high GHG footprints;
- Better understanding of options for structuring finance for investment in loss and waste reduction measures in value chains with high GHG footprints.

Catalytic investments
As with many other emerging topics, catalytic investments to demonstrate proof of concept for innovative climate-smart agri-food value chain developments and drive down costs and risks to attract commercial financing is required. Three focal areas to support such investment are likely to include research and development to demonstrate commercially viable options; incubation services to link businesses with sources of finance; and finance for mature, commercially viable business cases. Dedicated research programs with private sector co-financing or implementation work best when they target dynamic sub-sectors and business cases, and focus on clearly articulated knowledge or technology gaps that are relevant for private sector investments in climate-smart agri-food value chains (see Text box 9). In-depth analysis of technical feasibility, costs and benefits (including GHG mitigation benefits), and business models for replication and scaling can support both companies and financing institutions to identify investments with attractive adjusted returns.

[19] See, for example, a study on the effects of loss of preferential EU market access for beef from Botswana (ODI 2007).

[20] http://www.fao.org/save-food/en/

Enabling climate finance

The 2015 Paris Agreement may result in renewed interest of the private sector in voluntary cooperation related to the implementation of Nationally Determined Contributions (NDCs). Institutional investors, climate and development finance institutions, and commercial banks can play critical roles in supporting private investment, by providing access to debt or equity finance, or by reducing investment risk through guarantees or other forms of finance. Some financial institutions are planning to significantly increase investment in low-carbon and climate resilient growth.[21] Despite the fact that 103 out of 160 countries include agriculture in their NDC, there are very few climate-smart agri-food investment funds, lending streams from climate finance institutions with an agri-food focus, or successful agri-food proposals under the Green Climate Fund (GCF). Accelerating climate finance investments will require dedicated research and public investment to reduce the perceived risks by the private sector, and support to the private sector to structure and attract investments, particularly in agriculture-dominated economies where commercial lending is not widely available. Awareness of the central importance of livestock to the global GHG emission pathway is rising among the staff of climate finance institutions, but awareness of the need for dietary change may reduce the perceived attractiveness of investments in productivity-enhancing measures in the livestock sector. To date, dialogue between international agencies working on climate-agriculture issues and climate finance institutions has been limited. Diverse efforts are needed to seek common ground on the value of investments in the sector.

[21] http://www.odi.org/comment/10201-climate-finance-agreed-paris-cop21

Text box 15. Key areas for research to enable private sector investment in demand-side GHG mitigation measures

Dietary change:

- Better understanding of the effects of fiscal measures on the agri-food sector.

Food loss and waste:

- Analysis of lessons learned and best practices from public-private dialogue to support agri-food sector engagement with environmental issues;
- Analysis of technical feasibility, costs and benefits (including GHG mitigation benefits), and business models for replication and scaling of food loss and waste reduction measures in value chains with high GHG footprints;
- Better understanding between professionals in agriculture and in climate finance institutions on the business case for investment in supply- and demand-side agricultural mitigation options, with a particular focus on issues related to livestock.

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Appendix 1:
Livestock production, consumption, emissions and health related data from CCAFS focal countries

Country	Total population (million) [a]	Agriculture value added as % of GDP [b]	Livestock as % of agricultural GDP [c]	% agricultural emissions from livestock [c]	Per capita kcal available from animal products[d]	Obesity rate [e]	Rates of raised blood pressure [e]	% mortality due to cardio-vascular disease or diabetes [e]	Is there a multi-sectoral NCD strategy? [e]	Is there a national dietary promotion strategy? [e]	Is there an NCD surveillance system? [e]
Ethiopia	91.7	42%	36%	92%	133	1%	26%	10%	no data	no data	no data
Tanzania	47.8	32%	25%	69%	140	5%	31%	11%	no data	no data	no data
Uganda	36.3	27%	22%	83%	177	4%	34%	10%	No	No	No
Kenya	43.2	30%	48%	97%	279	4%	29%	9%	No	No	No
Senegal	13.7	16%	24%	64%	184	7%	32%	13%	No	No	No
Niger	17.20	37%	43%	96%	253	2%	42%	10%	No	No	No
Mali	14.9	40%	46%	72%	404	4%	26%	13%	No	No	No
Ghana	25.4	22%	8%	45%	135	8%	27%	20%	Yes	Yes	No
Burkina Faso	16.5	34%	29%	85%	163	2%	29%	14%	No	No	No
Peru	30	7%	35%	85%	281	16%	21%	24%	No	No	No
Guatemala	15.1	12%	22%	89%	244	19%	22%	19%	Yes	Yes	No
Colombia	47.7	6%	51%	89%	522	17%	27%	31%	Yes	Yes	No
Honduras	7.9	14%	37%	92%	430	18%	24%	29%	No	No	No
Nicaragua	6	21%	50%	94%	289	22%	25%	36%	No	No	No
El Salvador	6.3	11%	43%	83%	377	26%	22%	29%	No	No	No
Lao PDR	6.6	28%	16%	70%	192	3%	22%	24%	No	No	No
Cambodia	14.9	30%	13%	40%	226	2%	17%	26%	No	Yes	Yes
Vietnam	90.8	18%	25%	36%	491	2%	23%	36%	No	Yes	Yes
India	1240	18%	26%	64%	213	2%	21%	28%	No	Yes	No
Bangladesh	155	16%	13%	46%	91	1%	24%	20%	Yes	Yes	No
Nepal	27.5	34%	27%	75%	176	1%	24%	25%	No	No	No
Average		**23.55%**	**30.56%**	**74.58%**	**257**	**7.97%**	**26.11%**	**20.81%**			
Minimum		**6.30%**	**7.71%**	**35.80%**	**91**	**1.10%**	**17.00%**	**9.00%**			
Maximum		**41.90%**	**50.86%**	**96.73%**	**522**	**25.80%**	**41.50%**	**36.00%**			
Regional averages									**Total countries in each region with a policy**		
East Africa		32.73%	32.93%	85.08%	182	3.65%	29.83%	10.00%	0	0	0
West Africa		29.78%	30.03%	72.39%	228	4.66%	31.22%	14.00%	1	0	0
Latin America		11.82%	39.72%	88.71%	357	19.77%	23.58%	28.00%	2	2	0
Southeast Asia		25.40%	18.07%	48.71%	303	2.13%	20.77%	28.67%	0	2	2
South Asia		22.53%	22.46%	61.86%	160	1.47%	23.03%	24.33%	1	2	0

[a] data for 2012 from WHO (2014); [b] data for most recent year available from data.worldbank.org; [c] calculated from data for 2008 from FAOSTAT; [d] data from FAOSTAT food balance sheets; [e] data for 2008 from WHO (2014); [f] data for 2014 from WHO (2014).

Most emissions from the agri-food sector occur in the agricultural commodity production stage. Livestock have been highlighted as a major source of current greenhouse gas (GHG) emissions and projections suggest strong future growth in livestock products. Recent studies suggest that supply-side GHG mitigation options in agriculture will be insufficient to prevent further increases of GHG emissions and that demand-side measures, such as dietary change and reductions in food loss and waste, may have a larger technical mitigation potential than supply-side measures.

This report provides an assessment of the availability and effectiveness of demand-side measures, with a focus on developing countries.

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