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Climate change mitigation and food loss and waste reduction: Exploring the business case

Duncan Gromko

Gulbahar Abdurasulova

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Authors

Duncan Gromko (Corresponding author)
duncan.gromko@unique-landuse.de
UNIQUE forestry and land use GmbH

Gulbahar Abdurasulova
gulbahar.abdurasulova@unique-landuse.de
UNIQUE forestry and land use GmbH

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Contact information

CCAFS Program Management Unit
Wageningen University & Research
Lumen building
Droevendaalsesteeg 3a
6708 PB Wageningen
the Netherlands
Email: ccafs@cgiar.org

Front cover photo

Maria, a farmer from Sabilo Village in Babati District, Tanzania demonstrates proper storage of maize using PICS bags to her fellow farmers. She is among the many smallholder farmers benefitting from Africa RISING project's post-harvest interventions. Photo credit: Gloriana Ndibalema/IITA.

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Abbreviations and acronyms

CLP	Critical loss point
CO_2	Carbon dioxide
FLW	Food loss and waste
FSC	Food supply chain
GAIN	Global Alliance for Improved Nutrition (program)
GEMS	Growth and Employment in States (program)
Gt	Gigatons
IFPRI	International Food Policy Research Institute
IRR	Internal rate of return
ISB	Munjal Institute for Global Manufacturing
kg	Kilogram
LLP	Low loss point
MCC	Milk collection centre
MDTL-SL	Multi-Donor Trust Fund for Sustainable Logistics
NCCD	National Centre for Cold-chain Development
NIRSAL	Nigeria Incentive-Based Risk Sharing System for Agricultural Lending
NKCC	New Kenya Cooperative Creameries
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PASS	Private Agricultural Sector Support
PICS	Purdue Improved Crop Storage
SDG	Sustainable Development Goal
UHT	Ultra-high temperature
WRI	World Resources Institute

Currencies mentioned in the study and their conversion into USD as of October 2018 (EU currency converter)

KES	Kenyan Shilling currency, 1 USD = 101.76 KES
NGN	Nigerian Naira currency, 1 USD = 307.39 NGN
TZS	Tanzania Shilling currency, 1 USD = 2294.35 TZS
USD	United States Dollar currency

Glossary

Food means any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance that has been used in the manufacture, preparation or treatment of "food" but does not include cosmetics, tobacco, or substances used only as drugs (FAO/WHO 2001).

Food loss and waste (FLW) refers to a decrease, at all stages of the food chain from harvest to consumption in mass, of food that was originally intended for human consumption, regardless of the cause (HLPE 2014).

Food losses refers to 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 (HLPE 2014).

Food quality loss or waste refers to a decrease of a quality attribute of food (nutrition, aspect, etc.), linked to the degradation of the product, at all stages of the food chain from harvest to consumption (HLPE 2014).

Food waste refers to food appropriate for human consumption being discarded or left to spoil at consumer level—regardless of the cause (HLPE 2014).

Internal rate of return (IRR) describes the profitability of the project based on the rate of growth of the investment.

Marginal abatement cost calculates the total value (either positive or negative) of the investment per tons of GHGs reduced. This is calculated by dividing the NPV of the investment by the tons of GHGs expected to be reduced during the lifetime of the investment. A negative marginal abatement cost implies that the investment has a positive NPV, i.e. it is profitable (WALGA 2014).

Net present value (NPV) is the sum value of expected cash flows of the investment, discounted to present terms.

Post-harvest loss refers to the decrease in quantity or quality of produce between harvest and the market (FAO 1994).

Summary

The carbon footprint of food loss and waste (FLW) is estimated to be up to 3.49 gigatons of carbon dioxide equivalent (gtCO_2e), representing up to 6–10% of total anthropogenic greenhouse gas (GHG) emissions (HLPE 2014). Addressing FLW can reduce the emission intensity of the agricultural system; i.e. the number of tons of GHG emissions per ton of food consumed. This is critical, as global demand for food continues to rise. In addition to climate change mitigation, there are environmental, social, and economic benefits associated with reducing FLW.

While development organizations have long promoted FLW measures, commercial uptake of FLW interventions lags in many developing countries. Supply chain analysis can identify opportunities for profitably reducing FLW. This study examines the business case for reducing FLW in three supply chains: dairy in Kenya, cereals in Tanzania, and tomatoes in Nigeria.

Most losses in the dairy sub-sector in Kenya occur at the production and processing stages, as milk is transported from farmer to cooperative and to local processor. Satellite coolers and farmer training programs can reduce the amount of time milk is exposed to high temperatures and unhygienic conditions. Coolers can potentially reduce losses during storage by 6%, while extension programs to introduce proper handling practices can reduce losses by 4.5%.

Approximately 10–20% of cereal production in sub-Saharan Africa is lost post-harvest, resulting in decreased farmer income and food insecurity on the continent. Farmer investment in hermetically sealed cereal storage bags can greatly reduce farmer losses. The bags protect cereals and other crops from insect infestation and other potential damages, reducing post-harvest loss from an average of 14% to less than 1%, and reducing emissions proportionally, or 0.02 tCO_2e per bag per year. Additionally, the bags enable farmers to store cereals, protecting them from volatile market prices and especially the typically low prices immediately after harvest.

Although Nigeria is the second largest tomato producer in Africa, up to 86% tomatoes are not consumed due to losses throughout the supply chain: during production, harvest, local collection centres, cross-country transportation, and at retail markets. Approximately 41% of tomatoes are lost during transportation alone, mostly because tomatoes are placed in large woven baskets, and then smashed as the baskets are stacked on top of one

Table ES1: Business cases that reduce food loss and waste

Measure	Annual food losses reduced	Break-even period	IRR	GHG emissions associated with reduced losses (tCO_2e)
Dairy in Kenya: Cooler	52,560 litres per cooler or 6% reduction	2 years	303% after five years (annual)	273
Dairy in Kenya: Extension services	65,610 litres per extension team or 4.5% reduction	1 year	72% after two years (annual)	341
Cereals in Tanzania: Hermetic storage bag	14 kg per bag or 14% reduction	3–6 months	23% after three years (monthly)	0.02
Tomatoes in Nigeria: Crate	252 kg per crate or 36% reduction	4 months	34% after three years (monthly)	0.02

Note: GHG reduction potential is proportionate to FLW reduction potential and does not reflect the embedded emissions of the intervention, i.e. the emissions of producing the cooler, crates, bags or providing services. A full life cycle analysis has not been done. Also note that emissions are calculated per unit of the loss-saving measure; i.e. for one cooler, extension team, storage bag, and crate.

another for the journey to Lagos. Replacing baskets with plastic crates can reduce losses from 41% to 5%, with proportional reductions in emissions, or 0.02 tCO_2e per crate per year.

Examining these three cases reveals profitable measures that can reduce the GHG intensity of agricultural production by reducing losses. Loss reduction ranges from 4.5% to 36%; internal rates of return (IRRs) range from 23% to 303%; payback periods from three months to two years; and emission reductions range from 0.01 to 341 tCO_2e. The dairy cases have the highest return on investment, higher upfront costs and longer break-even periods, implying a need for longer term financing. Bags in Tanzania and crates in Nigeria have relatively low upfront costs and seasonal break-even periods. Future studies should consider whether FLW interventions may indirectly increase emissions, partially offsetting benefits.

Profitability of FLW business models does not rely solely on the reduction of FLW for increasing revenues. In many cases, there are synergies between the reduction of FLW, improved quality, increased prices for businesses and farmers, or other profitability incentives. Improved quality, safeguarding against price fluctuations, and guaranteeing delivery of higher quantity all can improve the profitability of FLW interventions.

The biggest climate change mitigation impact in the three cases described here is via reducing emission intensity (i.e. tCO_2e per ton of food consumed), rather than by reducing the absolute quantity of emissions. While some FLW reduction measures also reduce the absolute amount of emissions, especially in the dairy sector, emission intensity should be the focus of FLW reduction work. Given increasing demand for food products, this is a critical means of mitigating global emissions.

These cases reveal a number of lessons for reducing FLW at large scales. Where a business model has been established, supporting businesses that profit from FLW reduction measures, such as a business that manufactures or sells plastic crates, may be the most effective means of scaling up. Even though an appropriate technology or product has been developed, there is still a lot of work to be done before it becomes widespread and used on a commercial basis. Investing in marketing strategies and business management skills can help to accelerate the uptake of a FLW intervention.

Lack of access to finance is a primary barrier to investing in FLW interventions across supply chains. In addition to general challenges in access to finance in the agriculture sector, many FLW investments have payback periods that are challenging for farmers with immediate cash needs, and appropriate credit is difficult for farmers to access. Absorbing the credit risk specifically related to FLW investments would be hugely helpful for increasing uptake of FLW measures. Additionally, increasing the business management capacity of involved businesses would also improve the adoption of FLW measures by reducing perceived credit risk.

Donor support has played a key role in developing FLW interventions at initial stages. The Gates Foundation, the Rockefeller Foundation, USAID, UK-AID, the World Bank, and many others have invested in early stage development of technologies and products that reduce FLW. This type of high-risk / non-commercial funding is key in the early stages of research, development, and deployment of new technologies.

A poor regulatory or enabling environment is consistently a barrier to scaling up FLW interventions. Health and safety and quality standards, in particular, can create conditions that enable FLW reduction measures to succeed. In some cases, the proper regulatory framework exists, but is not adequately enforced.

All measures are expected to benefit smallholder producers, either directly in the case of the hermetic bags and the dairy extension services, or indirectly in the case of tomato crates and dairy coolers. In the case of indirect benefits, the increase in revenues and profitability in the supply chain occur very close to the producer in the supply chain, and it is reasonable to expect that producers capture some benefits.

Business models for reducing FLW are not well understood at the level of specific interventions. More research is needed to investigate specific business models and the case for investing in those models. More research on business models is needed to understand where profits can be made on reducing losses and which actors are best placed to implement them. To address social justice and equity concerns, additional research should focus on gender-specific business cases.

1. Introduction

1.1 Benefits of reducing food loss and waste

Reducing food loss and waste (FLW) should play an important role in strategies to mitigate global climate change because of the scale of the impact of the agricultural sector on climate change. Addressing emissions from land use is key to achieving global climate change temperature targets (IPCC 2018). The carbon footprint of FLW is estimated to be up to 3.49 gigatons (gt) of carbon dioxide equivalent (CO_2e), representing up to 6–10% of total anthropogenic greenhouse gas emissions (HLPE 2014). Reducing FLW reduces the greenhouse gas (GHG) emission intensity of the agricultural system; i.e. the number of tons of GHGs per ton of food consumed. In order to realize its potential, measures to reduce FLW need to be rapidly scaled up across agricultural supply chains.

In addition to its impact on climate change, FLW has significant impacts on the global economy and food security. Researchers are still coming to grips with the scale of FLW; first estimates suggest that approximately one-third of all food produced is either wasted or lost, with a value of approximately USD 940 billion per year (FAO 2015). The food security challenge and negative environmental impacts of food production are likely to grow, as demand for food increases due to population growth (an additional 3.6 billion people by 2100) and increasing incomes in developing countries (UNDESA 2017). Global social trends, such as changing diets associated with greater wealth, are increasing demand and providing private sector investment opportunities for resource-efficient food production and consumption (Delgado et al. 2017).

Beyond the climate change and economic impacts, FLW is associated with environmental harms, namely increased waste, water use, soil erosion, and loss of natural resources and biodiversity due to the production of food (Table 1) (FAO 2014). Increase in demand for agricultural production is the main driver of deforestation and land degradation in many parts of the world. The impact of FLW on land degradation and deforestation is higher in developing countries, with 6.31 Gt of soil lost and 1.66 million ha deforested in 2013. FLW also contributes to climate change by causing avoidable GHG emissions. Quick facts on FLW are presented in Box 1.

Numerous examples have demonstrated that reducing FLW can generate a triple win for food security, for the environment, and for the economy (Hanson and Mitchell 2017). Decreasing FLW creates an opportunity to feed more people. Cutting losses and waste in half by 2050 could contribute to reducing the food gap by 20% (WRI 2013) and meeting the nutritional requirements of around one billion extra people (Kummu et al. 2012). Curbing FLW along the food supply chain also has multiple economic benefits, as it saves money for farmers, companies, and households.

Table 1: Main global environmental impacts of FLW in 2013

Environmental impacts	Unit	Global	OECD countries	Non-OECD countries
GHG emissions	Gt CO_2e	3.49	0.75	2.74
Land area	Million ha	0.9	0.21	0.7
Water use	Km^3	306	24	282
Soil erosion	Gt soil loss	7.31	1.0	6.31
Deforestation	Million ha	1.82	0.16	1.66

Source: FAO 2014. The estimates in the table are based on food production data and the resources needed to produce the food that is lost and wasted, i.e., water and land area necessary for agricultural production, soil erosion and deforestation (land-use change) associated with agricultural production, and GHG emissions.

Box 1

Quick facts on food loss and waste

- Initial estimates suggest up to one-third of all food is lost or wasted between production and consumption;
- The cost of lost and wasted food globally is estimated at USD 940 billion per year;
- Lost and wasted food consumes a quarter of all water used by agriculture annually;
- The cropland size that was necessary to produce lost and wasted food equals the size of China;
- Lost and wasted food generates an estimated 8% of global greenhouse gas emissions; and
- Lost and wasted food would be the third greenhouse gas emitter in the world after China and the United States.

Source: Food Loss and Waste Protocol 2018

Sustainable Development Goal (SDG) Target 12.3 calls for cutting per capita global food waste in half at retail and consumer levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030. The progress of implementation of SDG Target 12.3 shows the potential of various actors, and especially business, to contribute to achieving the global FLW target and addressing climate change mitigation at large scales. One example is the global coalition of leading agricultural companies, the Global Agri-business Alliance, and its Food and Agricultural Product Loss Resolution, under which the members aim to reduce their rate of food loss by 50% by 2030 (Lipinski et al. 2017). Another big development is a global call to action by The Consumer Goods Forum to promote consumer education of labelling and labelling standardization by the year of 2020.

While the topic of reducing FLW has been extensively addressed by research and practitioners, there has been less focus on understanding specific businesses' motivations for reducing FLW. Donor-supported programs have made important advancements to reduce FLW, but these interventions have not always been adopted at scale, due to commercial barriers and a poor enabling environment. Understanding businesses' motivation to reduce FLW and reducing barriers to further investment in FLW reduction are key steps to accelerating private sector investment and scaling up efforts. Relatively small amounts of public investment or policy shifts can encourage significant private investment to reduce FLW. Other studies show that FLW reduction measures can be highly profitable, while contributing to climate change mitigation and improving food security (Clowes et al. 2018; Hanson et al. 2016; Hanson and Mitchell 2017; Kiff et al. 2016; Sathguru Management Consultants and FAO 2017a–d).

A study on the benefits of a food waste reduction program at pre-consumption stage across 42 hotels found that the benefit-cost ratio of such programs was 7:1 over a 3-year time frame, with no correlation with the hotel's market segment or geography (Clowes et al. 2018). In addition to the financial business case for FLW reduction, other studies have illustrated how reducing FLW: (a) increases the efficiency of the food supply chain resulting in increased efficiency of GHG emissions per unit of food consumed (emission intensity) and (b) reduces the release of GHG emissions from decomposition (Nash et al. 2017).

This report analyses research to date on the business case for reducing FLW and associated climate change mitigation. The report takes a deep dive into three interventions to reduce FLW via commercial means; milk spoilage in Kenya, grain storage in Tanzania, and tomato transportation in Nigeria. The report concludes by recommending how international development organizations, national governments, private sector investors, businesses in agricultural supply chains, and other stakeholders can address barriers to commercialization and accelerate adoption of FLW reduction measures in ways that also achieve social equity and environmental sustainability.

1.2 What is FLW?

FLW is defined as a reduction in mass of the edible food items produced for human consumption (FAO 2011). It takes place at each stage of the food supply chain (FSC): production, post-harvest and storage, processing, distribution, and consumption. Losses occur at early stages of the FSC, and waste occurs at later stages, closer to consumers (Delgado et al. 2017; FAO 2011; HLPE 2014; Lipinski et al. 2013). However, the precise boundary between food waste and food loss is somewhat arbitrary, and making this distinction does not serve to advance FLW reductions.

Another potential point of disagreement over FLW definitions is related to the disposal and/or use of waste. For example, is food waste that is disposed of in a landfill equivalent to food waste that is composted? In such a case, the distinction should be based on the FLW impact that is being targeted. From a food security perspective, food waste in a landfill is more or less equivalent to food waste that is composted, but from a GHG emissions accounting perspective, the two have different implications.

The reasons for losses at production, post-harvest, and processing stage are various: spoiling, inadequate storing conditions, lack of refrigeration, lack of packaging, etc. (FAO 2011; Segrè et al. 2014). For example, fruits bruise during picking; edible produce degrades due to fungus or disease; and milk is spilled during processing or transportation (Lipinski et al. 2013). The FLW that takes place at the distribution and consumption stages of the FSC are mostly referred to as food waste (Alexander et al. 2017). Examples of food waste are sorting out edible produce, produce expired before purchase, sorting out produce due to quality, and produce that is purchased and cooked but not eaten. Consumer preferences play a large role in FLW, as food is often discarded for aesthetic reasons even if it is safe for consumption. Additionally, unnecessary overconsumption of calories is a type of waste. While reducing unnecessary overconsumption would not reduce the GHG emission intensity of agricultural production, it would reduce agricultural production and associated emissions overall. Description of FLW at each stage of the FSC is presented in Table 2.

This analytical work adopts a broader definition of FLW, starting from total harvest of produced food, including non-human food uses and inedible produce, until calories that are overconsumed (Figure 1). A holistic definition looks at the entire agricultural and livestock production system to identify inefficiencies. This definition includes the loss of agricultural residues that have impacts on the overall food security situation, although residues are not edible food, (Alexander et al. 2017). Overconsumption, i.e. intake of more calories than required, is recognized as an inefficiency of the food system (Alexander et al. 2017; Bajželj et al. 2014; Segrè et al. 2014) and as a public health concern (Kiff et al. 2016; Lipinski et al. 2013). Accounting for non-edible and overconsumption losses represents a broader view of the agricultural system that captures opportunities for improving efficiencies throughout the whole agricultural supply system, including both production practices and consumer preferences (Alexander et al. 2017).

Table 2: Examples of food loss and waste along the food supply chain

<table>
<tr><th>FSC stage</th><th>Description of FLW</th><th>Loss or waste</th></tr>
<tr><td>Agricultural production</td><td>Unharvested crops, mechanical damage, and/or spillage during harvesting, fishing discards, waste of agricultural residues etc. (FAO 2011).</td><td rowspan="3">Food loss</td></tr>
<tr><td>Post-harvest and storage</td><td>Spillage and degradation during handling, storage and transportation between farm and distribution, etc.</td></tr>
<tr><td>Processing</td><td>Spillage and degradation during industrial or domestic processing.</td></tr>
<tr><td>Distribution</td><td>Both losses and waste in the market system, including wholesale markets, supermarkets, retailers, and wet markets (FAO 2011; Kummu et al. 2012).</td><td rowspan="2">Food waste</td></tr>
<tr><td>Consumption</td><td>Household-level waste from food spoilage and overconsumption of nutrients (Alexander et al. 2017).</td></tr>
</table>

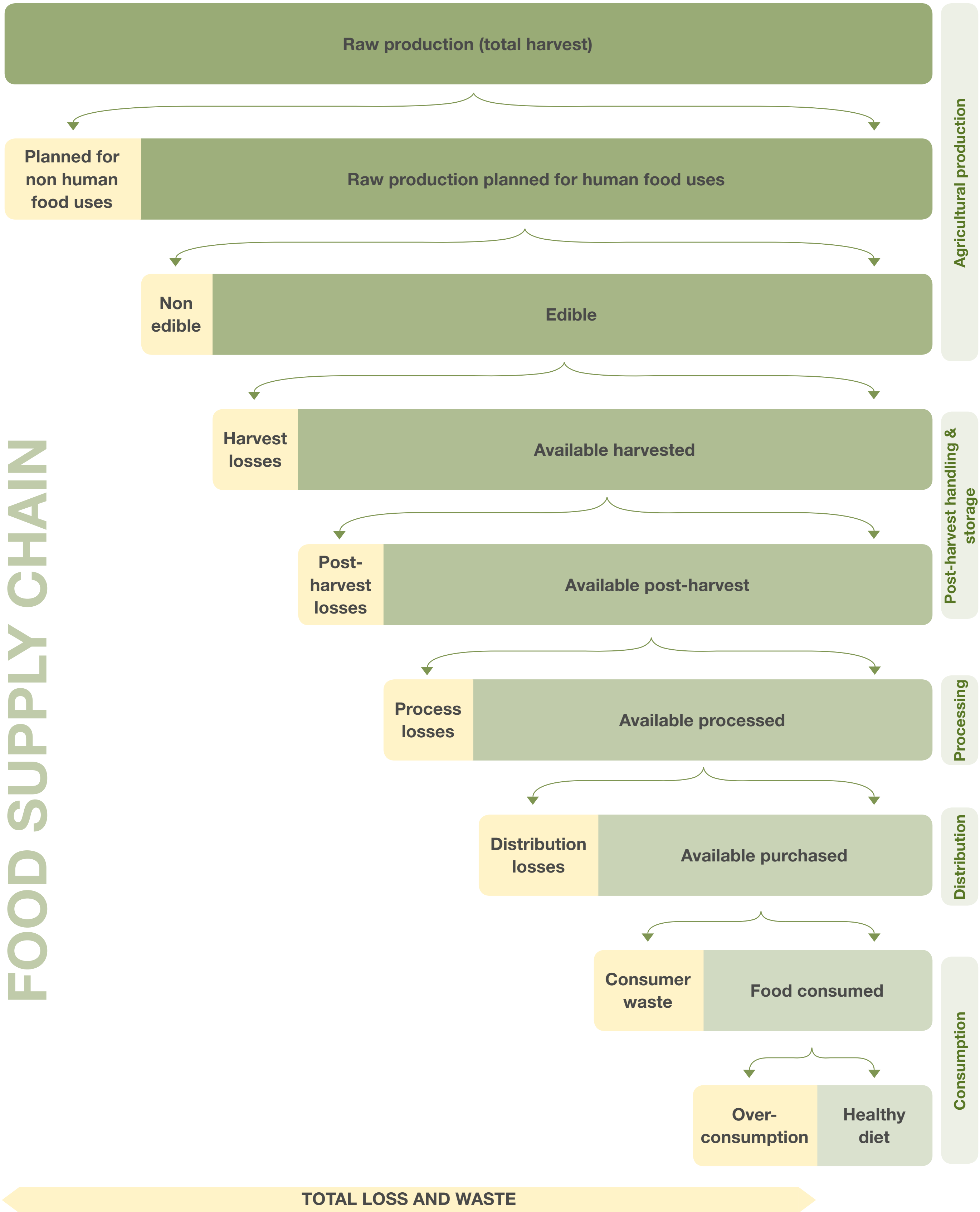


Figure 1: Framework for defining FLW in the food system along the stages of the food supply chain.

Source: Adapted from HLPE 2014.

1.3 Measuring FLW

As discussed above, definitions for measuring FLW vary widely. How FLW is conceptualized has implications for how FLW is measured, which in turn raises difficulties comparing FLW estimates to another issues. For example, in addition to loss in mass, i.e. quantitative loss, FAO recognizes a qualitative loss of the food as the food quality decreases (FAO 2014). Deterioration of product quality can happen during harvesting, on-farm activities, post-harvest storage or distribution phases. Product quality deterioration also has economic and health implications: the price of produce can decrease due to reduced quality, and the nutritional value can be compromised and/or unsafe for consumption.

Differentiation between quantitative and qualitative FLW also impacts whether FLW is measured in weight, calories, nutritional, and/or economic values (Delgado et al. 2017). Measuring FLW in mass or calories reveals different results. For instance, a FAO study on FLW found that 32% of global food produced for human consumption in 2009 was lost or wasted (FAO 2011). The same data converted into calories revealed that global FLW in terms of energy amounted to approximately 24% of all food produced (Lipinski et al. 2013). The difference in measuring weight versus calories is due in part to the water weight in food. For example, 100 grams of fresh apricots contains 60 kcal while 100 grams of dried apricot contains 274 kcal (Foodnutritiontable.com n.d.). Common quantification methods are presented in Box 2. The FLW protocol recommends measuring FLW based upon food weight (Hanson et al. 2016).

Estimating and accounting for FLW reductions enables calculating the extent to which the interventions reduce GHG emissions. A common way to calculate GHG emission reduction is estimating the emission intensity of items produced. GHG is reduced through increased efficiency of the FSC, which results in increased efficiency of GHG emissions per unit of food produced (Nash et al. 2017). Another consideration regarding the climate impact of FLW reduction measures is the avoided GHG emissions from the decomposition of FLW—as agricultural products decompose, they produce methane, a potent GHG.

Box 2

Common methods for quantifying FLW

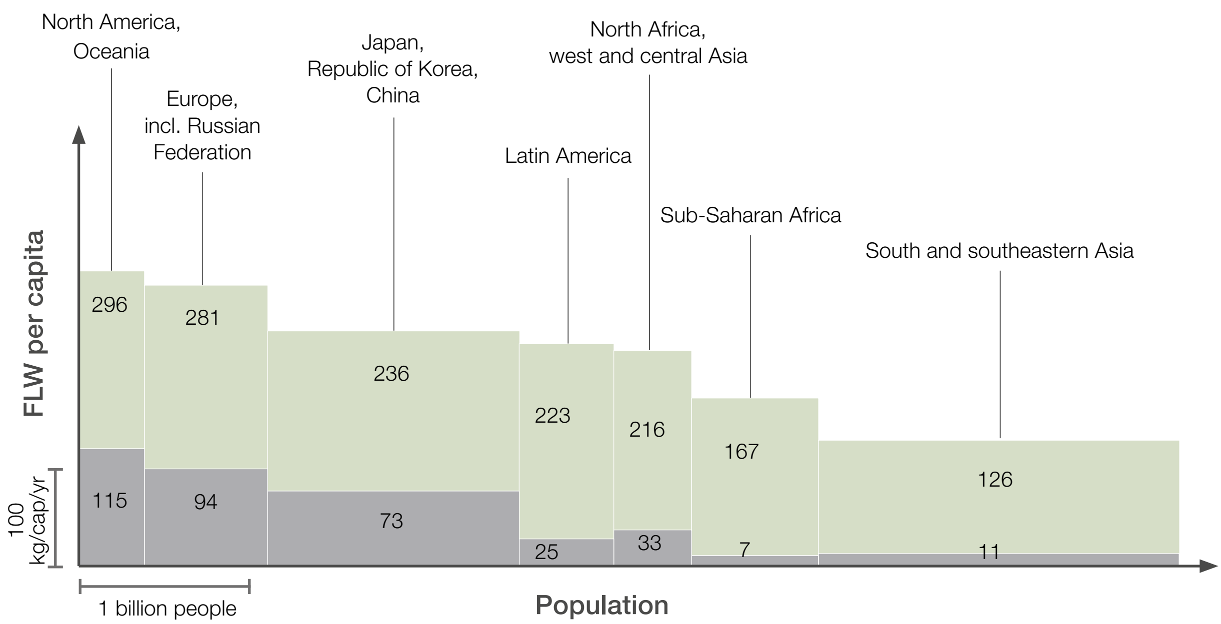
1. **Direct weighing:** Using a measuring device to determine the weight of FLW.
2. **Counting:** Assessing the number of items that make up FLW and using the result to determine the weight; includes using scanner data and visual scales.
3. **Assessing volume:** Assessing the physical space occupied by FLW and using the result to determine the weight.
4. **Waste composition analysis:** Physically separating FLW from other material in order to determine its weight and composition.
5. **Mass balance:** Measuring inputs and outputs alongside changes in levels of stock and changes to the weight of food during processing
6. **Modelling:** Using a mathematical approach based on the interaction of multiple factors that influence the generation of FLW.
7. **Proxy data:** Using FLW data that are outside the scope of an entity's inventory (e.g., older data, FLW data from another country or company) to infer quantities of FLW within the scope of the entity's inventory.

Source: Hanson et al. 2016.

1.4 Where does FLW take place?

The degree and types of FLW vary among geographic regions. Regional assessments of FLW found that FLW takes place more 'near the fork' in industrialized regions and more 'near the farm' in developing countries (FAO 2011; Hanson and Mitchell 2017; HLPE 2014; Lipinski et al. 2013). Figure 2 shows the level of FLW per capita in different regions. Industrialized countries produce a larger volume of FLW than sub-Saharan Africa or South and Southeast Asia. More losses occur at the production stage in sub-Saharan Africa (167 kg per capita) and in Asia (126 kg per capita) than in other regions. While losses at the production stage are still high for industrialized countries, the proportion of food waste at the consumption level is higher than in developing countries. For example, average per capita food waste at the consumption level of the FSC in North America and Oceania is 115 kg per capita and 7 kg per capita in sub-Saharan Africa (Figure 2).

Assessments of FLW in terms of calories and energy show similar distribution of FLW between post-harvest and consumer levels. In developing regions, the share of FLW in terms of calories is much higher at the production and post-harvest stages (Figure 3) (Hanson and Mitchell 2017). In industrialized countries of North America, industrialized Asia, and Europe, the degree of FLW is higher at the consumer level, ranging between 45 and 60% of total loss.



The X-axis represents the population of a region of group of countries. The Y-axis shows per capita FLW in the given region. The grey part distinguishes consumer waste from post-harvest losses within regional food loss and waste. For each region, the area of the rectangle represents total regional FLW.

Figure 2: FLW per capita in different regions.
Source: Elaborated from HLPE 2014.

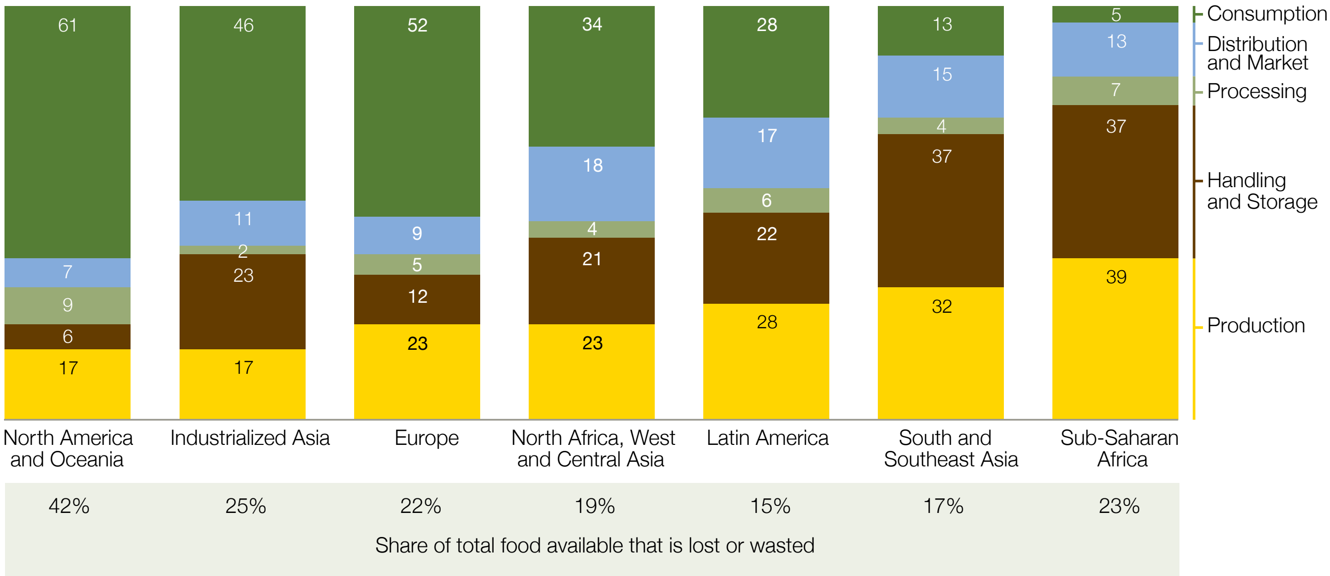


Figure 3: Percent of total kcal lost or wasted per region, 2009.

Note: Numbers may not sum to 100 due to rounding. Source: Hanson and Mitchell 2017.

1.5 How FLW has been addressed so far

Reducing FLW has been addressed through measures at different scales, such as introducing changes in enabling environment or technology. The enabling environment is addressed through adopting policies and regulations for improving market access, infrastructure for roads, energy, and markets in rural areas, pricing the use of natural capital or GHG emissions, education on food waste, capacity building, etc. Technology solutions are typically micro-solutions that are implemented by a single group of actors, for example, the adoption of refrigeration in the fresh vegetable FSC. Interventions along the FSC are often solutions that require collective action along the supply chain (HLPE 2014). A few FLW initiatives are described in Box 3.

FLW solutions exist at each stage of the FSC (Figure 4). Input choice, such as selecting crop varieties that are tolerant to weather stresses, suitable for specific locations, and attractive to the target market have great potential to reduce food loss. Equally important and effective are solutions like harvesting timing and scheduling to avoid preharvest losses. For instance, 25% of tomatoes are not harvested in Nigeria because prices drop so low that harvesting becomes unprofitable (Enclude and JMSF Agribusiness 2018). Processing and proper packaging of produce prolongs shelf life and contributes to reducing FLW. Storage technologies adapted to local conditions avoid the deterioration in quality of products and protect from destructive pests and other contamination. There is potential to reduce FLW at the transportation and distribution stages as well, for example through proper storage of produce during transit and at retail stores and warehouses, centralized distribution facilities, and efficient scheduling of transportation operations.

There is significant interaction between FLW reduction interventions and efforts to mitigate global climate change. By increasing the portion of food produced that is consumed, the GHG intensity of food production is decreased. Additionally, some FLW-reduction measures directly reduce GHG emissions, such as reducing milk spoilage.

Numerous studies have examined the benefits of reducing FLW. The World Resources Institute (WRI) calculated and explained the benefit-cost ratio of FLW-reduction measures using data collected from 42 hotels (Clowes et al. 2018). A ReFED Retail Food Waste Action Guide is a guide based on the United States Environmental Protection Agency (EPA) Food Recovery Hierarchy framework that recommends FLW-prevention with the greatest potential for profits (ReFED 2018). Too Good To Go (toogoodtogo.co.uk) is an example of a start-up

Box 3

Examples of FLW-related initiatives and projects worldwide

Waste and Resources Action Programme (WRAP) initiative was established in UK in 2000 to promote sustainable waste management. It became a registered charity in 2014.

Love Food Hate Waste Campaign, launched by WRAP in 2007 gives practical advice to households on how to reduce household food waste, for example by providing recipes for food leftovers, shopping planning advice, instructions for making food last longer, and so on. Assessments conducted within the Campaign found that the household food waste level in 2015 was 15% less than the level in 2007, equivalent to 2.7 billion pounds less food wasted in UK.

SAVE FOOD is a joint initiative of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), Messe Düsseldorf, and Interpack, the leading global trade fair for packaging and processes. The Community of Practice of the SAVE FOOD initiative serves as a global convener and an integrator of knowledge related to post-harvest loss (PHL) reduction. It is a platform to facilitate linkages and information-sharing amongst stakeholders and relevant networks, projects, and programs, and development cooperation-funded projects on post-harvest management.

Champions Initiative 12.3 is a coalition of executives from governments, businesses, international organizations, and other stakeholder organizations that seek to reduce FLW. These leaders share how FLW measures are being implemented around the world in order to address barriers and publicize success stories.

- Select varieties that meet consumer requirements, have longer shelf life, or are less vulnerable to droughts.
- Time planting and harvest according to market demand.

- Proper sorting of harvested crops.
- Market development for lower graded products.
- Improve storage of harvested crops.

- Dry or otherwise preserve products.
- Reduce contamination through proper handling practices.
- Labelling products according to consumer requirements.

- Proper handling during transportation.
- Improve logistics between actors.
- Refrigeration during transportation.
- Improve infrastructure.

- Promote seasonal consumption.
- Encourage appropriate portions at restaurant and household level.
- Distribution of unused food to other groups.

Figure 4: Examples of FLW interventions at five stages in the food supply chain.

Source: Adapted from Nash et al. 2017.

company that helps stores sell their surplus food and track avoided GHG emissions; it is based in Europe. A study on food loss at post-harvest stage in the state of Andhra Pradesh, India for four sub-sectors: chickpea, mango, milk and rice, commissioned by the FAO initiative SAVE FOOD, highlights the causes of food loss and proposes possible solutions applicable to each sub-sector (Sathguru Management Consultants and FAO 2017a–d). FAO also commissioned a series of case studies on reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries (FAO 2018).

Geographically, the cases primarily cover South and Southeast Asia, but there are also cases from industrialized countries and global cases. FLW-reduction cases from industrialized countries tend to focus on the distribution and retail stage, i.e. food waste. In developing countries, FLW solutions target post-harvest and storage stages of the FSC: for example, on improving harvesting techniques to minimize qualitative deterioration of produce and prolong shelf life via better storage practices, i.e. food loss. Information and communication technology (ICT) can minimize FLW throughout the FSC.

Indicators that illustrate the benefits of FLW interventions are benefit-cost ratio, the volume of FLW reduced, CO_2e saved, net returns, net present value, internal rate of return, and break-even point. Analysing FLW interventions is an important step towards attracting investments. From the information available, many FLW reduction measures are highly profitable and there is a commercial incentive for adoption.

While a few technologies may have impact if taken up by single groups of actors (such as farmers), implementation of most FLW interventions requires coordination among FSC actors and support from policy makers. For example, introduction of better harvesting tools and techniques must be supported by both farmers and intermediaries working with farmers, such as input suppliers, extension agencies, and farmers' cooperatives. Financial support, from either public or private actors in the value chain, is needed for initial investments that smallholder farmers are not able to afford. Arrangements of how this can function are context- and case-specific. A summary of published FLW business cases can be found in Table 3. In-depth case studies are presented in Chapters 3–5 of this report.

Table 3: Summary of business cases analysed in literature

FLW reduction case study, publisher, year	Sector; supply chain position; location	Description and source	FLW achieved	Profitability indicator (based upon estimated sales)
Chickpea value chain food loss analysis, FAO India study, 2017	Chickpea FSC; Post-harvest handling and storage; South Asia	The study assessed the expected qualitative and quantitative Critical Loss Points (CLPs) for each step of the chickpea FSC. The findings indicate a low level of losses across different stages of the supply chain. Reasons for low levels of losses: mechanical threshers for threshing, professionally managed dry and cold storage houses, wide adoption of single variety owing to uniform size and better processing efficiencies, good transport practices and conditions, fast rotation of small quantities at wholesale and retail stages. *Source: Sathguru Management Consultants, FAO. 2017a. Chickpea value chain food loss analysis: causes and solutions.*	Capacity building on storage practices with the farmers resulted in loss reductions of 1060 ton per year. No CO_2e reduction estimate was made.	The cost-benefit analysis for capacity building efforts reveals a cost of USD 570,400 per year. After costs, this investment is expected to result in annual profits of USD 320,000.
Milk value chain food loss analysis, FAO India study, 2017	Milk FSC; Post-harvest handling and storage; South Asia	The study investigated both formal and informal channels of milk supply. It found that the losses during the early and middle stages of FSC are higher. Major reasons: rejection at the milk collection centres and chilling centres due to non-compliance with quality standards and spillage losses during transportation. Milk loss could be reduced by introducing adulteration test kits at milk collection centres and continuous capacity building. *Source: Sathguru Management Consultants, FAO. 2017c. Milk value chain food loss analysis causes and solutions.*	Anticipated loss reduction is 1% (from 3% loss rate) for loss reduction through adulterant test kit (for implementation in 10 villages). No CO_2e reduction estimate was made.	The profitability of establishing 10 testing centres is USD 15,216 per year with 31% loss reduction. Calculations for solar implants (for cooling milk) at 9 milk collection centres revealed savings of USD 68,693. Costs are estimated at USD 4,620.
Mango value chain food loss analysis, FAO India study, 2017	Mango FSC; Post-harvest handling and storage; South Asia	The study analysed quantitative and qualitative mango food loss at individual stages of supply chain by identifying CLPs and Low Loss Points (LLPs). Recommendations include training on proper harvesting techniques and post-harvest care, low cost packaging structures for fresh fruit FSC, developing standard conditions and methods for traditional ripening, and farm and post-harvest services by private entities. *Source: Sathguru Management Consultants, FAO. 2017b. Mango value chain food loss analysis: causes and solutions.*	With the introduction of plastic crates rental, anticipated loss reduction is 30% (loss rate 10%) and anticipated loss reduction is 15,985 ton per year. No CO_2e reduction estimate was made.	Profitability of training on farm: USD 3,329,067 per year. Profitability of plastic crates: USD 500,562 per year. The cost of training on harvesting: USD 27,800 per district a year; plastic crates on rental basis USD 2,856,304 per district a year.
Rice value chain food loss analysis, FAO India study, 2017	Rice FSC; Post-harvest handling and storage; South Asia	The study identified key factors of losses in the rice FSC: mechanized farming and threshing at the farmer level (7–10%) and qualitative losses during storage at mills and warehouses due to moisture. Suggested interventions: End-to-end linkage in the supply level (farmer producer organizations), capacity building of harvester operators, and hermetic storage or silos to reduce losses during storage. *Source: Sathguru Management Consultants, FAO. 2017d. Rice value chain food loss analysis: causes and solutions.*	The capacity building of farmers and machine operators on varieties to minimize shattering of grains would reduce loss by 10% (loss rate 6%). With the hermetic cocoon, the expected loss reduction is 80%. No CO_2e reduction estimate was made.	Profitability of training and capacity building of combine harvesters: USD 18,977,902 per year; cost of intervention (training of trainers): USD 149,840; profitability of hermetic bags USD 27,810,092 per year without government subsidy and USD 27,629,908 with 50% government subsidy. The cost of hermetic cocoons with no subsidy from government: USD 1,663,200,000; with 50% government subsidy USD 831,600,000.

Table 3 continued

FLW reduction case study, publisher, year	Sector; supply chain position; location	Description and source	FLW achieved	Profitability indicator (based upon estimated sales)
Cold chain development for fruits & vegetables in India, Kinnow Cold Chain Study, 2016	Mandarin FSC; Post-harvest handling and storage; South Asia	The study analysed a supply chain for a high-yielding hybrid variety of Mandarin (Kinnow) from Abohar in Punjab in northern India to Bangalore in southern India to demonstrate the costs and benefits of deploying a cold chain. The report assesses investment in cold chain by analysing profitability of the investments. *Source: ISB, NCCD. 2016. Cold chain development for fruits & vegetables in India, Kinnow cold chain study.*	Results show that investment in the cold chain—specifically precooling and transport refrigeration equipment—can reduce food loss by 76% and CO_2e emissions by 16%.	The profitability of the investment is not reported.
Case study of bananas in Sri Lanka, FAO, 2018	Banana FSC; Post-harvest handling and storage; South Asia	Bananas are perishable and susceptible to damage. Losses in the traditional banana supply chain in Sri Lanka average 28.8% (9% at farmer level, 5.4% at wholesaler and 14.4% at retailer level). Improved post-harvest handling of bananas included: dehandling using a dehandling tool, packing of dehandled bananas in a plastic crate with thin polystyrene foam, and transport of bananas using plastic crates. With the improved handling practices, total loss was reduced to 19.05% from 28.81% (34% reduction). *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved handling practices, loss is reduced by 34% (from 28.8% to 19.1%). No CO_2e reduction estimate was made.	The use of improved handling practices resulted in the net return of USD 0.38 per kg compared with only USD 0.33 per kg for the farmer with traditional practices. The wholesaler had the net return of USD 0.48 per kg, while with traditional practice, the return was USD 0.43 per kg. At the retailer level, the net return was USD 0.59 per kg for bananas handled using the improved practice and USD 0.44 per kg for bananas handled using traditional practices.
Case study of cauliflower in Nepal, FAO, 2018	Cauliflower FSC; Post-harvest handling and storage; South Asia	The traditional practice of leaving 5 to 7 leaves attached to the long stem of cauliflower results in 28–30% loss at the farm level (the leaves account for 25 percent of the weight of cauliflower sold. Bulk packaging in either plastic sacks or plastic bags results in 6% loss from damage related to transport and packaging and 5% weight loss at the level of the wholesaler. At the retailer level, deterioration and weight loss was around 40%. Improved practices included harvesting at correct stage of maturity, trimming leaves and stems, bulk packing in plastic crates with plastic liner between layers of curds, and wrapping single curds in low density polyethylene film. *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved post-harvest practices, the loss is reduced by 64.8%. No CO_2e reduction estimate was made.	Farmer benefits of trimming: net returns USD 0.19 per kg vs USD 0.13; for the wholesaler US 0.031 vs USD 0.002, for the retailer USD 0.23 vs USD 0.05. Benefits of using plastic crates for bulk packaging of produce for transportation for wholesaler was USD 0.24 in net return (per kg sold) versus plastic sacks with no trimming USD 0.18. Benefits of wrapping cauliflower curds with plastic film for retailer was USD 0.19 in net return vs USD 0.05 (no wrapping).

Table 3 continued

FLW reduction case study, publisher, year	Sector; supply chain position; location	Description and source	FLW achieved	Profitability indicator (based upon estimated sales)
Case study of mandarin in Nepal, FAO, 2018	Mandarin FSC; Post-harvest handling and storage; South Asia	Mandarins have a relatively long shelf life and can be stored under ambient conditions for almost 11 days. The highest loss was incurred at the retail level equaling to 13.04% (6.84% weight loss and 6.20% deterioration). At the level of the wholesaler and retailer, the total post-harvest loss was 20.29%. Improved post-harvest practices were introduced through pilot demonstrations such as: use of harvesting tools with a bag attached at the end; harvesting fruits at the correct stage of maturity; sorting and grading; coating with vegetable oil in combination with detergent; and proper bulk packaging in plastic crates. Total losses in improved supply chain were reduced by 56.9% (43.4% for wholesaler and 64.6% for retailer). *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved supply chain, loss is reduced by 56.9%. No CO_2e reduction estimate was made.	The benefit from improved post-harvest practices (maturity) was small for the wholesaler. The retailer net return was USD 0.69 per kg sold (vs USD 0.62).
Case study of mango in Bangladesh, FAO, 2018	Mango FSC; Post-harvest handling and storage; South Asia	With the traditional method of harvesting ('pick and throw'), losses amounted to 16.6%. Loss was low at the wholesale level at 1.9% mainly from weight loss. Weight loss at the retail level was 10.9%, and loss from decay during the 5-day retail period was 25.1%. Key loss-reduction steps were: improved harvesting tool; sorting using plastic crates as field containers; and disease control with hot water treatment. With the improved mango supply chain, the total loss reduced by 66.2% (53.3% at the retailer level and 15.8% at the wholesale level). *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved mango supply chain, loss is reduced by 66.2%. No CO_2e reduction estimate was made.	Additional gross income with the improved practice of hot water treatment was USD 77.10 on day 3 and USD 219 on day 5.
Case study of snap beans in Sri Lanka, FAO, 2018	Snap bean FSC; Post-harvest handling and storage; South Asia	Losses in the traditional supply chain were 8.05% at the farm and 17.9% at the wholesale level. Traditional handling practices include: poly-sack as harvest or field container, sacks of snap beans carried on shoulder at the collection centre, and 50 kg capacity poly-sacks of snap beans in the wholesale market. Operations to improve practices in the snap bean supply chain included: harvesting pods at the correct stage of maternity, sorting based on external appearance, and bulk packing in 15 kg capacity plastic crates. With the improved supply chain, the total loss reduced by 30.4% (59.2% at the wholesale level and 19.9% at the retailer level). *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved handling practice in supply chain, the loss is reduced by 30.4%. No CO_2e reduction estimate was made.	With the use of plastic crates, farmers would have net returns of USD 0.66 per kg compared with only USD 0.56 when using poly-sacks as transport containers. The wholesaler obtained a net return of USD 0.68 per kg with the improved practice and USD 0.55 per kg with the traditional practice. The retailer's net returns were USD 0.93 per kg with the improved practice and only USD 0.85 per kg with the traditional practice.

Table 3 continued

FLW reduction case study, publisher, year	Sector; supply chain position; location	Description and source	FLW achieved	Profitability indicator (based upon estimated sales)
Case study of winter tomato in Bangladesh, FAO, 2018	Tomato FSC; Post-harvest handling and storage; South Asia	Losses at the wholesale level reached 16.7% mainly attributed to mechanical damage (abrasion, bruising, compression and cracks). At the retail level, loss amounted to 29.3% because of severe mechanical damage. Operations and improved practices in the winter tomato supply chain: harvested tomatoes in plastic pail and in the field plastic crates, trimming of long stem, washing in chlorinate water, and bulk packaging in 25 kg plastic crates. In improved supply chains, the total loss reduced by 94.3% (from 46 to 2.6%). 100% reduction in loss at the wholesale level and 91.1% at the retailer level. *Source: FAO. 2018. Case studies on managing quality, assuring safety and reducing post-harvest losses in fruit and vegetable supply chains in South Asian countries. Rome.*	With the improved handling practice in tomato supply chain, the loss is reduced by 94.3%. No CO_2 reduction estimate was made.	With the improved practice of using plastic crates, the wholesaler will have a net return of USD 0.11 per kg and only USD 0.09 employing the traditional practice. The net return for the retailer employing the improved practice is USD 0.23 per kg and only USD 0.16 (BDT 13.89) per kg with the traditional practice
Sohan Lal Commodity Management (SLCM), 2018 (sohanlal.in/ index.html)	ICT; Post-harvest handling and storage; South Asia	Agri Reach is Artificial Intelligence-infused technology, which is likely to reduce post-harvest loss for farmers considerably. The AI-driven process allows the company to monitor any of the 710 agri-commodities that they deal in, and micromanage their storage environment remotely. *Source: SLCM 2018. Retrieved from sohanlal.in/index.html*	The efficacy of the predictive engine and the study assessed that storage losses at the warehouses had reduced to 0.5% from 10%earlier. No CO_2 reduction estimate was made.	The profitability of the investment is not reported.
ReFED Walmart U.S. study, 2018	U.S. Retail Food Sector; distribution; North America	The guide is designed to help retail businesses understand the size of the food waste and provide industry-specific guidance on implementing food waste reduction solutions and recommendations. ReFED has adapted the EPA Food Recovery Hierarchy framework to categorize the solutions to reduce food waste, prioritizing prevention first, then recovery, and finally recycling, to maximize economic, social and environmental benefits. Solutions with greatest profit potential are all prevention solutions such as Improved Inventory Management, Cold Chain Management, Dynamic Routing, Enhanced Demand Forecasting, and Dynamic Pricing and Markdowns. *Source: ReFED. 2018. Retail Food Waste Action Guide 2018. Retrieved from http://www.refed.com/downloads/Retail_Guide_Web.pdf*	The Roadmap to Reduce U.S. Food Waste shows a path to a 20% reduction of food waste through 27 cost=effective, scalable solutions. No CO_2e reduction estimate was made.	The guide has developed into the Retail Solution Matrix to help retailers prioritize solutions based on two dimensions: i) profit potential: the net annual profit potential of a given solution, not including initial investment. ii) feasibility: a combination of the level of effort and the initial financial capital needed to implement a solution.
The business case for reducing food loss and waste: Hotels, 2018	Hospitality (hotels); distribution; global (42 hotel sites located in 15 countries[1])	The study analysed data of pre-consumer waste from 42 hotels sites, located across 15 countries. The hotels have introduced food waste reduction measures such as identifying food waste hotspots, monitoring food waste, new procedures on handling and storing, and redesigning menus. *Source: Clowes et al. 2018. The business case for reducing food loss and waste: Hotels. A report on behalf of Champions 12.3. Retrieved from https://champions123.org/wp-content/uploads/2018/04/Report_Hotels_The-Business-Case-for-Reducing-Food-Loss-and-Waste.pdf*	On average, the surveyed hotels achieved a 21% reduction of food waste by weight over a 12-month time frame. No CO_2e reduction estimate was made.	Benefit-cost ratio: 7:1 over a 3-year time frame. Within two years of implementing a program, 95% of sites recouped their investment. By reducing FLW, the average site saved over 4% on every US dollar of costs of goods sold (COGS).
Too Good To Go (TGTG), 2018 (toogoodtogo.co.uk)	Food Sector; Distribution; Europe	Too Good To Go (TGTG) is a European start-up that helps food stores sell their surplus food through TGTG free smartphone app. The initiative is active in eight European countries: Denmark, Norway, France, UK, Germany, Switzerland, Netherlands and Belgium. Through the app, 4 million meals have been saved, which equals to 7,000 tCO_2e saved. In less than 2 years, around 5,000 stores have joined the TGTG network. *Source: https://toogoodtogo.co.uk/en-gb/about-us*	Too Good To Go estimates that its users have saved over 2 million meals, equivalent to 7,000 tCO_2e.	There is a USD 47 annual fee for the food stores that includes everything from marketing, social media, service for the account and the app. For every portion that is sold through the app, TGTG gets USD 0.85.

[1] Australia, China, Germany, Hungary, Myanmar, Norway, Philippines, Poland, Singapore, Sweden, Thailand, United Arab Emirates, United Kingdom, United States & Vietnam.

2. Methodology

The information used in this report was compiled using desk research, phone interviews, and authors' existing knowledge from other project work. The authors began research for the report with an extensive review of existing literature on FLW. Based on this analysis, 15 potential business cases were selected for further study.

Follow-up interviews and availability of information led to the selection of the dairy supply chain in Kenya, maize supply chain in Tanzania, and tomato supply chain in Nigeria for further analysis as business cases. The authors prioritized cases based upon: their relevance in the country, perception of potential profitability, and potential to positively impact directly or indirectly smallholder farmers in developing countries. Additionally, the authors chose supply chains with high GHG intensity (dairy), medium intensity (horticulture), and low intensity (cereals). The authors present findings from the interventions at the intervention level and attempt to estimate the impact if the intervention were scaled up to the national level.

The GHG emissions estimates for the tomato and maize cases were calculated using the EX-ACT Tool (http://www.fao.org/tc/exact/ex-act-home/en/). The dairy case estimates were calculated based upon WRI data for emissions per litre (WRI CAIT 2.0 2017). It is important to note that full life cycle assessments of the supply chains, in order to calculate GHG emissions, were not conducted. GHG reduction potentials are based upon the GHG intensity of food produced in the value chain. The business cases that were studied in this report could have a number of impacts on GHG emissions that were not included in the authors' calculations. A critical example is the interaction between reducing FLW and consumption: it is conceivable that in reducing FLW and therefore the quantity of foods available on the market, consumption increases, with indirect impacts on GHG. The authors did not incorporate such broad, economic factors in their analysis. Moreover, the authors do not include the GHG impacts of producing the loss saving technology itself. For example, producing plastic crates under the Nigeria tomato case study would lead to GHG emissions—these are not included in the authors' calculations. Rather, the GHG analyses should be seen as narrow calculations of the GHGs associated with each quantity of food produced, and how this intensity can be reduced by reducing FLW. GHG intensity per quantity of food in the report is based upon net food production after the FLW reduction measure—additional losses may occur further in the value chain before consumption.

Cash-flow models were constructed using assumptions provided by interviewees and data found in literature. Input data for cash flow models comes from either interviews with stakeholders or globally available data. Estimates of internal rate of return (IRR) are calculated on a monthly or annual basis, depending on the cash flows of the business case. Break-even points are estimated based upon the time after which the initial investment can be repaid without including financing costs.

The specific cases were built partially using existing literature, but primarily by interviewing companies and other actors in the supply chain. The authors were not able to interview every key actor in each selected supply chain, and focused on key actors for implementing the intervention. For example, hermetic bag distributors were a key source of information in the hermetic bag case. Additionally, organizations indirectly involved in promoting the intervention (NGOs, international development organizations) were interviewed to better understand the context for the intervention.

3. Business case: reducing milk spoilage in Kenya

3.1 Context

Approximately 150 million households produce milk around the world. Milk is an important source of calories and income for small households, particularly in the developing world. Losses in the sector vary significantly by world region. In Europe, North America and Oceania, and industrialized Asia, most losses happen at the consumption level, when milk purchased by consumers expires before it is consumed. In developing countries, however, losses are more common at the production, post-harvest (transporting milk to processors), and distribution levels (Figure 5). Challenges in controlling bacteria are a primary reason for milk spoilage at these stages of the supply chain.

The dairy sector plays an important role in Kenya, with Kenyans consuming approximately 130 litres of milk per person per year, one of the highest rates in the developing world (Masembe 2015). Milk is expected to become more important as a source of protein in Kenya, with annual per capita consumption expected to be 220 litres by 2030 (Ministry of Livestock Development 2010).

Milk production is also expected to grow from 5.2 billion litres in 2017 to 12.6 billion litres by 2030. About 2 million farming households—or 35% of rural households—produce milk in Kenya. Women play a major role in dairy production throughout the country. About 70% of milk is produced on smallholder farms, and milk sales contribute significantly to farmers' incomes, including income for rural women. The sector is largely characterized by household consumption or selling milk directly; 47% of production is for household consumption, and 80% of production is consumed at household level or sold directly to consumers and not to a processor (Ministry of Livestock Development 2010). Most production is by smallholders with 2–3 cows. Furthermore, traditional consumption of milk in tea makes raw milk a favourable product.

Dairy cooperatives, owned collectively by dairy producers, play a critical role in organizing milk production in the country. Cooperatives typically help to organize the transportation of milk from their hundreds of members to nearby dairy processors. Dairy producers make regular financial contributions to the cooperatives and receive services in return. For example, cooperatives may sponsor technical extension visits for their members, organize input suppliers to engage with members, and offer financial services for members, either directly or in cooperation with a local bank.

Average dairy cow productivity is low (on average approximately 1,800 kg/cow/year, compared to 8,000–9,000 kg in Europe or 10,000 in the U.S. and Israel). In addition to reducing waste in the dairy supply chain, boosting productivity

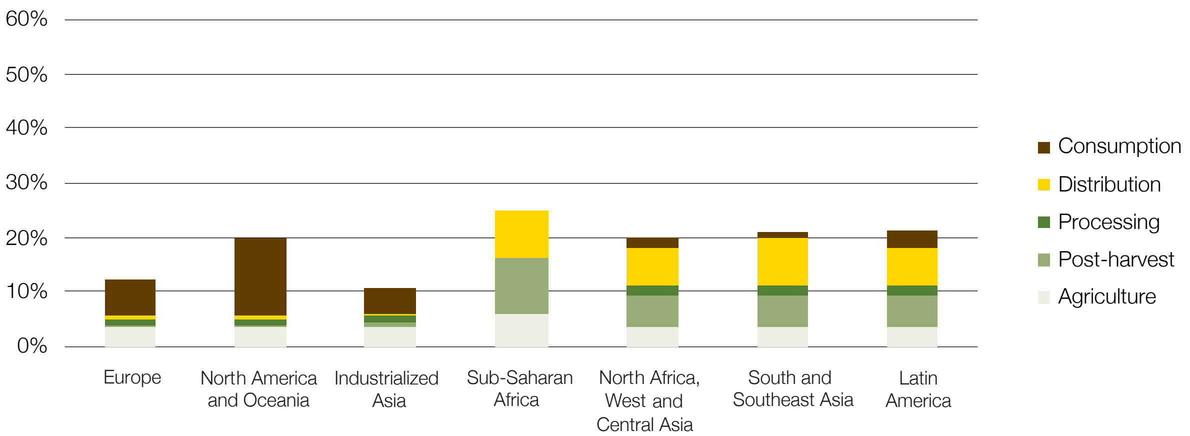


Figure 5: Percent of milk production wasted, by region and supply chain stage.

Source: FAO 2011.

is a key strategy for increasing production in the sector. Improving access to feed and animal husbandry practices are two of the most important ways that yields can be boosted while reducing GHG emissions (Erickson and Crane 2018).

Limited market access in remote areas located far from milk collection centres (MCCs) and low hygienic and food safety standards make milk spoilage and loss a primary challenge in the dairy sector in Kenya. Typically, milk that is processed is sent from producers to local MCCs and then to one of almost 600 cooling centres around the country. After cooling, milk is transported via trucks to 32 different processing plants, where it is pasteurized, separated, and homogenized. Total installed processing capacity is 2.9 million litres per day (Republic of Kenya 2013). Milk is sometimes treated with Ultra High Temperature (UHT) techniques or turned into powder before being distributed. Kenya dairy processors process approximately 600 million litres of milk per year (Wilkes et al. 2017).

New Kenya Cooperatives Creameries (NKCC) is Kenya's second largest milk processor, processing 160 million litres of milk per year and second only to Brookside Dairy in terms of production (Wambugu et al. 2011). NKCC secures its supply from approximately 54,000 farmers from 18 catchment areas around the country. The majority of NKCC suppliers are small-scale farmers, on average supplying the company with eight litres of milk per day (Ministry of Agriculture Livestock and Fisheries 2016).

The dairy sector is a significant source of GHG emissions in the country, although the share of GHG emissions is debated. For every kg of milk produced, approximately 5.2 kg of CO_2e are emitted (including enteric emissions and manure management), or 12.3 Mt CO_2e per year in Kenya based on national dairy statistics (WRI CAIT 2.0 2017). Kenya's total GHG emissions were 60.2 Mt CO_2e in 2013, meaning that dairy sector emissions represent approximately 20% of total emissions (USAID 2017). Other estimates suggest that dairy emissions are responsible for as much as 41% of total emissions in the country (Ainabkoi Dairy Farmers Cooperative Society personal communication 2018).

3.2 Reducing losses between the producer and processor

This business case was developed with knowledge gained from UNIQUE's long-term experience in the Kenyan dairy sector, literature review, and targeted interviews of producers, cooperatives, and service providers.

The dairy supply chain in Kenya is complicated, as milk passes through many actors in the formal market (Figure 6). Smallholder producers, who produce most milk in the country, deposit their milk in local MCCs before it is transported to processing plants. Milk is then sold through a variety of outlets.

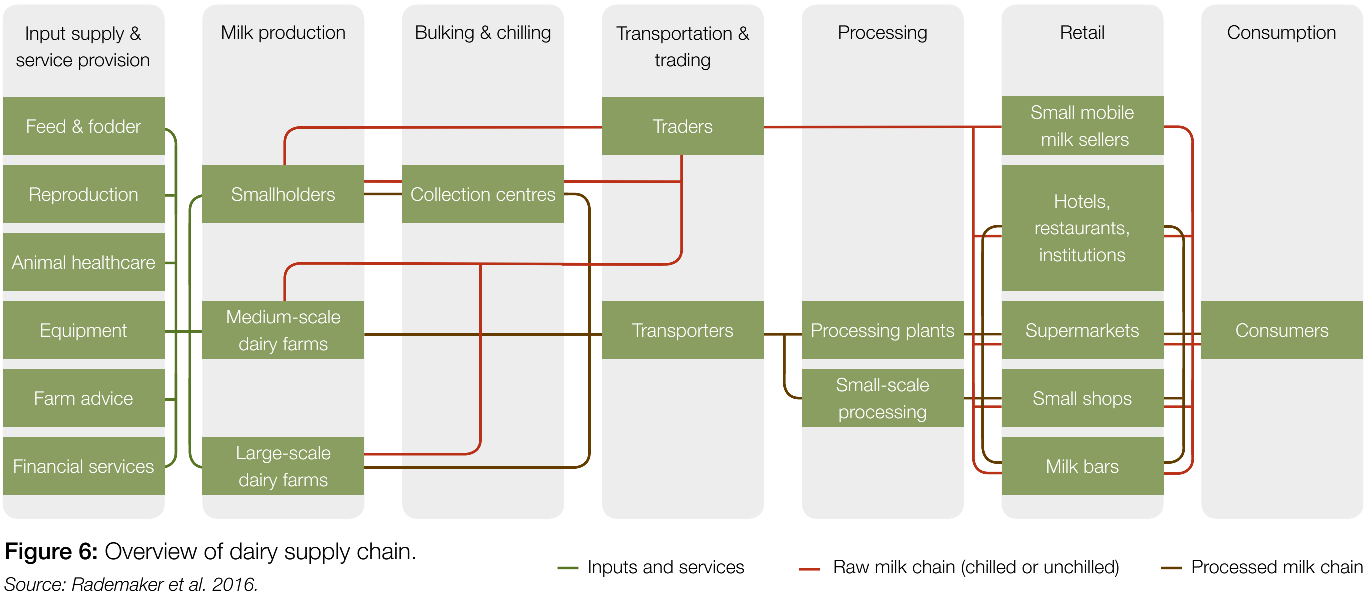


Figure 6: Overview of dairy supply chain.
Source: Rademaker et al. 2016.

Key losses happen between the smallholder producer and the processor. Milk is collected and transported in unhygienic conditions and exposed to high temperatures, leading to spread of bacteria and eventual spoilage. Recognizing the potential to increase milk supply, Kenyan milk processors have taken steps to reduce losses that occur before the milk enters their direct control. NKCC and other processors are supporting farmers to reduce losses through three specific measures:

- Processors pay a premium of USD 0.01–0.02 (KES 1–2) (assuming conversion rate of 0.0099 USD per KES) per kg of milk for farmer cooperatives that collect milk in coolers (The coolers are typically diesel powered). Coolers store milk at a lower temperature, reducing the amount of time that milk is exposed to high temperatures, thus decreasing bacteria levels.
- Processors pay a premium of USD 0.01–0.03 (KES 1–3) per kg of milk to farmer cooperatives for achieving certain volume-based targets. Participating in farmer training programs can enable farmers to boost productivity and reduce losses, ultimately allowing cooperatives to reach these targets. Clean milk production training modules focus specifically on milk quality and handling prior to collection.
- Processors pay a premium of USD 0.02 (KES 2) per kg of milk for milk that is transported in tankers. Tankers are meant to displace smaller aluminum cans that farmers use to transport milk. By using tankers, the amount of time that milk is exposed to unhygienic conditions and high temperatures is reduced, decreasing bacteria levels.

The mechanism by which NKCC and other processors support these loss-reduction measures—a price premium for farmers that adopt different practices—is noteworthy. ‘Side-selling’ and competition among milk processors for access to supply is a major challenge for milk processors in the country. By providing a subsidy, processors hope to increase supplier loyalty in addition to providing an incentive to reduce spoilage losses.

It is important to recognize that these measures are only relevant for the formal milk market, where milk is sold and processed. About 45% of milk—which is mainly collected during the evening milking—is retained for home consumption, the feeding of calves, or sold to neighbours. Evening milk is often referred to as “women’s milk” and is an important source of income for women.

3.3 Costs and benefits of loss reduction measures

3.3.1 Farmer cooperative costs and benefits

Farmer cooperatives help purchase equipment or implement extension service programs. It is important to clarify the underlying business model of cooperatives when analysing the costs and benefits. Farmer cooperatives typically buy milk from farmers at the same price that they sell it to processors. Cooperatives are entities owned by their members and do not, therefore, make money by marking up the price of milk. Rather, they meet their costs by charging their members membership fees. The proposed investments alter this business model: as they are adding value to the milk and receive a premium from the processor, cooperatives make a small margin on the milk they purchase.

The authors analysed the business case for three FLW-reduction interventions in the dairy sector in Kenya: coolers, farmer training programs, and tankers. Data were not available to construct a cost-benefit analysis for investment in tankers.

Coolers require high upfront investment costs and generate continual operational expenditures, primarily for energy. The purchase of the cooler and its installation cost approximately USD 5,942 (KES 600,000), and yearly operational costs are USD 8,318 (KES 840,000). Coolers have an average capacity of 5,000 litres and are typically operating at approximately 50% capacity. Farmer cooperatives benefit financially from increasing the amount of milk that they can sell to a processor and from the price premium. Coolers reduce spoilage losses at the cooperative from 6.4% to 0%. Costs and benefits with and without the cooler from a farmer cooperative perspective are summarized in Table 4. Data were not available to evaluate the costs and benefits of solar energy-powered coolers versus diesel-powered coolers; this remains a gap in analysing coolers.

The investment in coolers is extremely attractive under the authors' assumptions. CAPEX and OPEX increases are quickly paid back through increases in revenue. Revenues increase due to reduction in losses (52,560 litres per year) and an increase in price paid by the cooperative (USD 0.01 per litre). The investment can be repaid within one year and has an annual IRR of an estimated 303% over five years. The investment is most sensitive to the assumption that coolers reduce losses from 6.4% to 0%. If losses are not reduced so dramatically, the investment becomes less profitable; for example, the IRR drops to 154% if losses with coolers are reduced to 3%. The investment is also sensitive to the amount of milk delivered by farmers; if farmers produce half of what they are assumed to produce (7.5 litres per day from 2 milking cows), the annual IRR drops to 77% over five years.

Participation in farmer training programs has a much different cash flow profile than coolers. There are no upfront capital costs; operational costs take the form of paying the salaries of extension agents (USD 792 or KES 80,000 per month for three extension agents) and their costs (USD 297 or KES 30,000 per month). Cooperatives benefit from the premium paid for meeting volume targets, between USD 0.01–0.03 (USD 0.02 per litre is assumed for calculations). Using the authors' assumptions, milk productivity increases by 1.5 litres per animal per day during the first year; during the second year, daily productivity increases by an additional 1.5 litres per animal. Increasing the total volume and price paid per litre increases the net cash flows of cooperatives by USD 782 (KES 79,000) per month during the first year and USD 1316 (KES 133,000) per month during the second year after paying for the extension agents. This results in an IRR of 72%. The slight increase is extremely sensitive to the premium received by the cooperative; if they meet lower volume targets and receive a premium of only USD 0.01 per litre, net cash flows become negative: USD 153 (KES 15,500) during the first year and USD 114 (KES 11,500) during the second year after paying for the extension agents. Table 5 summarizes the costs and benefits of farmer training programs.

Table 4: Difference in cash flow associated with use of milk cooler vs. no cooler (USD)

Year	0	1	2	3	4	5
Capital expenditure (CAPEX)	-5,942					
Operational expenditure (OPEX)		-8,318	-8,318	-8,318	-8,318	-8,318
Revenues		26,346	26,346	26,346	26,346	26,346
Net difference	-5,942	18,029	18,029	18,029	18,029	18,029

Source: Authors' calculations. Note: Assumption that coolers reduce losses from 6.4% to 0% is used.

Table 5: Summary of costs and benefits of farmer training programs

Indicator	Amount
Extension agents' salaries	USD 792 per month for three agents
Extension agents' costs	USD 297 per month
Increase in revenues year 1 and year 2	USD 782 and USD 1,316
2-year IRR (annual)	72%

However, it is important to note that the business model of cooperatives is affected by more than the direct increase in revenues from the premium. Cooperatives cover a significant portion of their costs through membership fees. Having extension programs is likely to increase cooperatives' membership fees, and thus the fees that they earn. This dynamic is difficult to predict and has not been incorporated into the cash flow analysis.

Aside from the benefits to the cooperatives, farmers additionally benefit from increased productivity that is associated with improved animal husbandry practices. Productivity may double, and spoilage losses may be reduced by 4.5%. Although the cooperative making the investment does not capture these benefits, their member farmers benefit significantly.

The use of tankers implies a high upfront cost of USD 91,080 (KES 9.2 million) for farmers for the purchase of the tankers. There are also some operational costs to support drivers and maintenance to the tankers: USD 297 (KES 30,000) per month for a driver's salary and per diem, USD 990 (KES 100,000) per month for fuel, and USD 149 (KES 15,000) per month for maintenance (Ainabkoi Dairy Farmers Cooperative Society personal communication, 2018). Tankers have a capacity of 10,000 litres, but they typically operate at 70% capacity. The main benefit to a cooperative from purchasing a tanker and transporting the milk from the cooperative to the processor comes in the form of a premium from the processor of approximately USD 0.02 (KES 2.5) per litre. The authors are not able to estimate the reduction in losses from using a tanker and thus the expected cash flows of such an investment. More research is needed to evaluate the profitability of investing in a tanker.

3.3.2 Processor costs and benefits

The authors were unable to estimate the financial benefits to processors of the three measures with the available data for two reasons. First, processors do not track the total change in quantity of milk purchased as a result of the measures. One important benefit to processors is improved supplier loyalty. However, this is difficult to attribute exclusively to the subsidies provided by a processor. Second, estimating the financial benefits of these measures would require a better understanding of a processor's own business model, and how increased access to supply translates into revenues and profits. More information is required to demonstrate the financial efficacy of these programs from a processor's perspective. The premium processors offer to farmer cooperatives are the driving force behind cooperatives' incentives to invest. Understanding their profit margins and the incentives they can afford would inform how they can optimally influence cooperatives to reduce losses.

3.3.3 GHG emissions reduction

The GHG intensity of milk production in Kenya is high, so measures that reduce losses from spoilage have corresponding high potential to reduce GHG emissions. The reduction in losses from each measure and associated GHG reductions are shown in Table 6. Emissions savings for coolers are based on the use of one 5,000-litre capacity cooler. Emissions savings for extension services are based on hiring three extension workers to work with members of one dairy cooperative. The authors have been unable to estimate loss reduction potential from the use of tankers, so this is not included in Table 6 and is noted as a future information need. There is significant potential to reduce GHG emissions through coolers and extension programs. Assuming that all milk produced nationally could be shifted to using coolers and extension services, then approximately 1.7 and 1.2 Mt of CO_2e per year could be saved. This is an overestimation as some milk is currently stored in coolers and produced by farmers that receive training on safe handling practices, but it shows the scale of the emission reduction potential.

In addition to emissions reduction potential, another indicator of efficient use of financial resources for GHG mitigation is also relevant: marginal abatement cost, or the marginal cost of implementing mitigation. The marginal abatement cost is similar to: dividing the Net Present Value (NPV) associated with a measure by the tCO_2e that it will reduce. A negative marginal abatement cost means that the revenues associated with the measure are greater than the costs after applying an appropriate discount rate. Higher negative numbers reflect higher profitability per tCO_2e.

Table 6: Emission intensity benefits from reducing milk spoilage

Measure	Annual losses reduced	GHGs emitted at national level associated with losses	Marginal abatement cost
5,000-litre cooler	52,560 litres per cooler	1.7 Mt CO_2e	-USD 36 per tCO_2e
Three-person extension services team	65,610 litres per extension team	1.2 Mt CO_2e	-USD 3 per tCO_2e

Source: Authors' calculations. Note: the negative marginal abatement cost means that the revenues associated with the measure are greater than the costs after applying an appropriate discount rate. Higher negative numbers reflect higher profitability per tCO_2e.

3.4 Barriers to scaling up

Despite the effectiveness of reducing losses and associated profitability, these three measures are not widely implemented in NKCC's supply chain nor amongst processors in general. The authors have identified three barriers to scaling up.

Access to finance. Finance is a major barrier to implementing these loss reduction measures at a larger scale, particularly for the coolers and tankers. Farmers and farmer cooperatives have difficulty borrowing from local banks for a number of reasons: including insecure land title, insufficient collateral, informality of businesses and their accounting practices, and perception of risk of the agricultural sector. In addition to these general investment barriers for the sector, borrowing for coolers and tankers specifically presents a challenge. Both require significant upfront investment; and medium- and long-term credit is even more difficult for farmers and farmer cooperatives to access. Though some cooperatives have managed to borrow money in order to purchase tankers and coolers, this practice is not widespread.

Access to markets and the informal sector. The measures evaluated are only relevant to milk that is sold to processors via formal markets; they do not address milk that is produced for self-consumption or sold informally, such as from household to household. Poor infrastructure and general difficulty in accessing markets limit farmers' ability to participate in cooperatives and sell to processors. Women generally have a more difficult time participating in formal milk markets because of these conditions. As noted earlier, milk sold on informal markets is known as "women's milk" because women control its sale and often the associated income.

Farmer cooperative management capacity. Lack of capacity is another important barrier to scaling up the loss-reduction measures described in this report. Kenyan dairy farmers are typically very small, with most farmers owning 2–3 cows and producing 5–10 litres per day. Because such farmers are too small to deal directly with processors, they are organized into cooperatives to collect, transport, and sell milk. Farmer cooperatives face a significant challenge in management, organizing their members and ensuring that they deliver consistent quantity and quality of milk. Loyalty and trust of cooperative members in management has been a key challenge for many cooperatives. Farmers often sell milk on the side if they might receive a slightly higher price, but they expect cooperatives to run profitably and to purchase the milk also when the demand is low. Financial management skills of cooperatives are also low, particularly bookkeeping skills. Both of these factors make it more difficult for a cooperative to invest in tankers, coolers, and training programs. In broad terms, youth are exiting the dairy sector and agriculture at large for employment in urban areas. The lack of youth in management positions in farmer cooperatives is a long-term barrier for the improved management of cooperatives.

Lack of incentives. Disincentives for processors to invest directly in loss-reduction measures is also a barrier to scaling up. Given cooperatives' challenges in accessing finance and management capacity, an alternative model to rolling out loss-reducing measures would be for processors to assume the upfront costs of tankers and coolers. NKCC or Brookside could, for example, purchase a tanker and manage delivery of milk themselves. NKCC is much more creditworthy than a typical farmer cooperative so there is an argument that they are better placed to make these investments themselves.

However, two factors discourage processors from taking these steps. First, it would be difficult for a processor to ensure that the tanker is not used to sell milk to a competing processor due to side-selling and competition from other processors. Second, this scenario would translate into additional liabilities in the form of high-risk farmer cooperative loans for processors.

3.5 Solutions

Improve financial access. Access to finance, a major barrier to farmer cooperatives to investing in loss-reduction measures, could be partially addressed through credit guarantees or other risk-absorption measures that would encourage banks to lend to cooperatives. Additionally, since access to finance is limited by the financial management capacity of cooperatives, business training for the aging population of financial managers in cooperatives is needed to improve cooperatives' bankability. Providing education and incentives for youth to stay in rural areas and manage these businesses themselves would also help to address the problem.

Support the regulatory environment for informal markets. Quality standards for informal milk markets exist, but they are difficult for the Kenya Dairy Board to enforce. At the time of this report, there is a move to require that all informal milk be pasteurized. Support to ensure that all informal milk meets quality standards would reduce losses associated with transport and storage.

Develop additional logistical solutions. Much of the loss in the dairy market is associated with the complex logistics of collecting milk daily from remote farmers and protecting it from spoilage until it can be processed. Blockchain technology based on smart phone applications can improve communication between farmers and cooperatives and better organize milk transportation and traceability. Motorbikes or other mobile transportation could be fitted with coolers in order to reduce the time until milk is chilled, which could be a niche for young farmers. Such new solutions will require upfront investment in research and development and broad understanding of the market.

Understand and address actors' incentives. The costs and benefits of loss-reduction measures are spread among farmers, farmer cooperatives, and processors, creating a complex set of incentives for actors. For example, cooperative business models, including whether they generate revenues through member fees or by adding value to milk, are not well understood. A better understanding is needed of cash flows among these actors and what incentives they have to invest in loss reduction. This would help to identify price or investment bottlenecks that could then be addressed with public policy.

4. Business case: storage of cereals in Tanzania

4.1 Context

Global production of cereals in 2018 is projected to decrease by 62.5 million tons from 2017 levels, reaching total production of 2,595 million tons.[2] Meanwhile, utilization of cereals continues to grow and is expected to be 2,646 million tons in 2018/2019, a 1.2% increase from the previous year. Continued growth of consumption combined with production challenges is putting pressure on cereal stocks (FAO 2016). Cereal production in North and South America, is characterized by large-scale farmers of 50 hectares or more, while farmers in Africa and Asia tend to be smaller (Altiereri and Koohafkan 2008). In sub-Saharan Africa, cereal production accounts for approximately 25% of incomes (World Bank 2011).

Maize is a staple crop for most Tanzanians and is grown as both a subsistence and cash crop. Most maize farmers are smallholders with 1–3 hectares of land. As most maize production in the country is rainfed, it is increasingly vulnerable to extreme weather events, and production varies significantly year to year. In late 2016 and early 2017, for example, maize prices doubled when supplies fell during prolonged drought. Prices subsequently returned to normal levels when the rains returned (FAO n.d.).

Production of maize and other grains is highly variable throughout the year based on agro-ecological conditions. Some regions in Tanzania have two growing seasons per year, while other regions have only one harvest per year. Annual weather fluctuations result in glut and scarcity times (see Figure 7), creating large fluctuations in the selling price of maize throughout the year. Farmers in a particular region usually harvest at the same time, creating a glut, and sell maize for as low as USD 9 (20,000 TZS) per 100 kg. A few months after harvest, farm-gate prices spike to as high as USD 35 (80,000 TZS) per 100 kg.

The large price fluctuations for maize and other grains are primarily the result of lack of access to dependable storage. While losses in cereals supply chains happen at many steps in the chain—including harvesting practices, pest and insect infestation, contamination by aflatoxins, fungus, or pathogens (often related to drying)—this case focuses on post-harvest losses related to storage. In sub-Saharan Africa, physical losses amount to 10–20% of harvested volumes and USD 4 billion in losses annually (World Bank 2011).

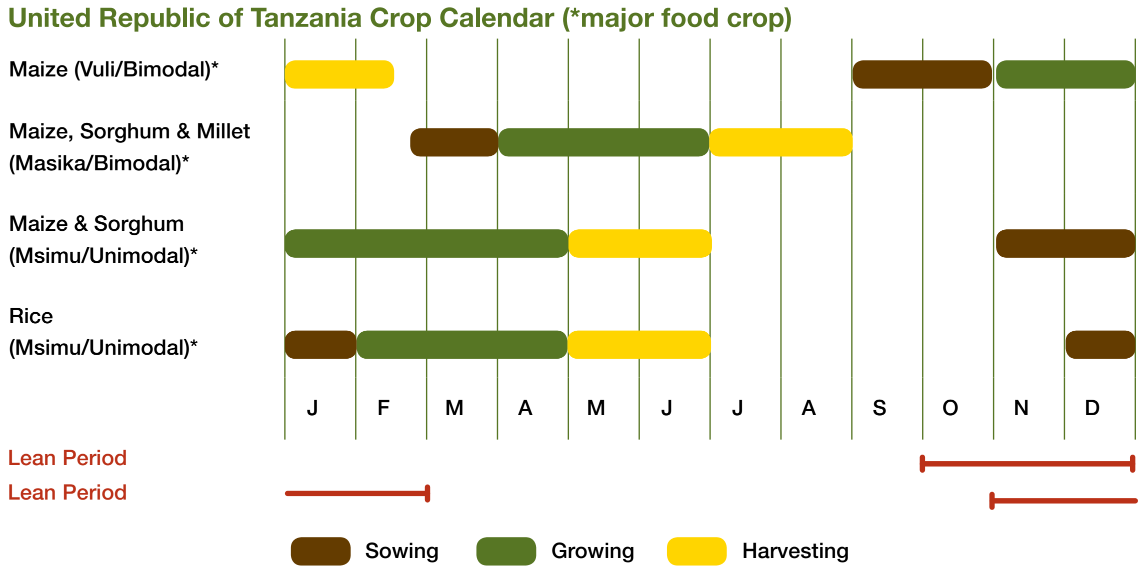


Figure 7: Sowing, growing, harvesting, and corresponding cereal-scarcity periods in Tanzania.

Source: FAO n.d.

[2] Cereals are defined as crops harvested for dry grain only (excluding, for example, green harvest of forage) and broadly include wheat, rice, barley, maize, rye, oats, millet, and sorghum, among others.

4.2 Reducing losses in the supply chain

This case investigates the potential to reduce losses in grain storage through the introduction of hermetically-sealed bags. The case was developed through interviews with international financial institutions, local banks, companies that distribute hermetic bags, and NGOs involved in the sector. Private Agriculture Sector Support (PASS) and Vestergaard were particularly important sources of information.

In recognition of the importance of maize and the potential to improve livelihoods through reducing post-harvest losses, a number of programs have developed and introduced technologies that reduce losses in storage. A Purdue University researcher developed a "Purdue Improved Crop Storage" (PICS) bag in the 1980s in an effort to specifically reduce post-harvest losses in cowpeas. The Gates Foundation has supported the use of PICS bags through three 5-year projects in Burkina Faso, Ethiopia, Ghana, Malawi, Nigeria, Tanzania, and Uganda. Although the bags were initially designed for cowpeas, they are now being used for many other crops, and particularly with maize in Tanzania.

With the third phase of PICS wrapping up in 2019, efforts are focused on turning the product into a commercial business. A Tanzanian company, Pee Pee Tanzania Limited (PPTL), started to manufacture and distribute PICS bags in 2014. Commercial sales started in 2015 with 130,000 units, and reached 780,000 units in 2017. A UK-AID program, Food Trade, has assisted with marketing and distribution, and Purdue University has funded demonstrations in 3,500 villages.

A second technology provides similar benefits. A Dutch parent company, Vestergaard, has developed many goods used for development work, such as blankets and water purification technology. In 2004, Vestergaard received a recommendation from the World Health Organization Pesticide Evaluation Scheme (WHOPES) for bed net technology to counter malaria. Knowledge about stopping insects for bed nets was then transferred to grain storage, and they developed ZeroFly Storage Bag. ZeroFly Hermetic stops insects through two means: killing insects that come in contact with insecticide on the outer bag and by suffocating insects and larvae in the bag through a hermetic seal. Vestergaard has sold 40,000 units.

Although these companies have grown quickly and managed to sell many bags, the total potential market is far from being met. If all grain production was stored in hermetic bags, Tanzania's population of 55 million people would require 40.15 million bags (Mtaki 2017).

4.3 Costs and benefits of storage bags

4.3.1 Farmer costs and benefits

The authors considered the costs and benefits of hermetically sealed grain storage from the perspective of the farmer for this analysis. The business models of manufacturers and distributors are also important to promote scaling up; but data was not immediately available through the authors' desk study.

There are two potential financial benefits for farmers that adopt hermetically sealed bags. First is the reduction in grain that is infested by insects or otherwise lost post-harvest. Losses without bags are estimated to be 14%, while losses with bags are less than 1%. Second is that the easy ability to store grain enables farmers to protect themselves from the extreme price volatility of the maize market in Tanzania. In the current situation, farmers in a region all harvest and sell at the same time, often causing prices to crash. Farmers with bags can wait to sell until prices are high.

In practice, farmers are likely to benefit from a combination of both factors. For the purpose of modeling benefits, the authors focus on the second factor, allowing farmers to sell at higher prices. A simple cash flow model for five months is shown in Table 7 below. The authors assume that without bags, farmers can sell for USD 0.11 (250 TZS) per kilo and, five months later, can sell for USD 0.31 (700 TZS) per kilo, losing 0.5% during storage.

The promoted bags last for three years (although farmers use them for longer). Assuming that farmers harvest one maize crop per year and use the bag for three years, the monthly IRR of the investment is 23% over three years.

In addition to the actual purchase of the bag for USD 2.2 (5,000 TZS), using the bag implies forgone income of USD 11 (25,000 TZS) at harvest. Both of these figures are significant for small-scale farmers. The farmer earns his/her money back once prices have increased after the harvest glut passes.

4.3.2 GHG emissions reduction

The emission intensity of grain production is relatively low, especially compared with the Kenya dairy case. Emissions per ton of grain produced are calculated to be 1.07 tCO_2e per ton. However, the low cost of the hermetic bags and their effectiveness at reducing waste by 14% mean that they can still generate significant emission reductions when implemented at large scales. The reduction in losses from introducing bags and associated GHGs are shown in Table 8.

4.4 Barriers to scaling up

Despite PPTL, Vestergaard, and others' success in rolling out hermetically sealed bags, the potential to scale up bag use by orders of magnitude remains. A number of barriers are slowing scaling-up efforts.

Convincing farmers of bag effectiveness. Communicating the benefits of the bag to farmers is one of the main challenges to increasing adoption rates. Demonstration efforts have been partially successful in convincing farmers of the effectiveness of the bag, but demonstrations are costly. There are reports that some vendors are using untested technology and promoting them as hermetically sealed bags, which could further undermine farmer confidence in the technology.

Distribution logistics. Many farmers are living in remote areas, often with poor infrastructure. PPTL estimates that adoption rates of bags are high within a 7-kilometre radius of a vendor. Establishing networks with vendors across remote areas of Tanzania is costly and time consuming.

Table 7: Cash flow for 100 kg hermetically-sealed bag (USD)

Month	0	1	2	3	4	5
Purchase bag	-2.2					
Lost revenue		-11				
Gained revenue						30.65
Net cash flows	-2.2	-11				30.65

Source: Authors' calculations based on interview with Vestergaard in 2018.

Table 8: GHG benefits from reducing grain losses

Loss reduction over three years for one bag	GHGs emitted at national level associated with losses	Marginal abatement cost
42 kg	0.75 $MtCO_2e$	-USD 91 per tCO_2e

Source: Authors' calculations using EX-ACT Tool. Note: the negative marginal abatement cost means that the revenues associated with the measure are greater than the costs after applying an appropriate discount rate.

Access to finance. Purchase of the bag and forgone revenue from selling maize immediately after harvest are significant costs to small-scale farmers. Farmers often have immediate cash needs, such as school fees, that they need to meet. Financial intermediaries such as Equity Bank and the Tanzania Postal Bank (TPB) Bank are the primary institutions lending to the agricultural sector, but small-scale farmers are often not seen as creditworthy. Interest rates of 15–20% are common. Agro-dealers often provide some inputs to farmers on credit basis, but typically over very short terms. The International Finance Corporation (IFC) is currently supporting a risk guarantee program to reduce local banks' risk in lending to Tanzanian farmers for FLW reduction measures, amongst other investments.

Price risks. Adopting hermetically sealed bags is a sort of speculation by the farmer, as he or she is counting on the price of maize to increase in order to justify the investment and delay in immediate income. If prices do not soar as normal, the investment would be a poor one. At prices below USD 0.23 (525 TZS) per kilo and a discount rate of 15%, the investment no longer has a positive net present value. If hermetically sealed bags were widely adopted across the entire country, price fluctuations of maize would decrease, reducing the benefits of price speculation.

4.5 Solutions

There are several solutions that could accelerate the use of hermetically sealed bags for the storage of maize and other commodities.

Enforce quality standards. Government enforcement of quality standards, and associated marketing, would reduce risk that vendors promoting poor technology as hermetically sealed bags could destroy farmer confidence in the technology.

Subsidize distribution and marketing. Though PPTL has been able to quickly increase distribution networks, increasing the number of distributors and vendors represents a significant upfront investment with significant risk. Moreover, demonstration sessions required to encourage farmers' adoption of bags cut into profit margins of bag distributors. Subsidizing distribution and marketing of bags would reduce these barriers and accelerate scaling up.

Absorb credit risk. Given the clear profitability of the use of the bags and the quick return on investment, the bags are a sensible investment for a farmer with access to capital. Though some farmers have access to cooperative unions or other farmer organizations, this is rare and even those farmers experience difficulty accessing loans. Given that farmers are generally perceived as having questionable creditworthiness by banks, it may be more appropriate that distributors or vendors provide credit to farmers for bag use. Rolling out such a program would likely require the credit risk of farmers to be absorbed by public finance.

Hold maize as collateral. Another way of reducing the risk of lending to farmers is to change the location of maize storage to use maize as a type of collateral. In such a scenario, a grain trader or other entity with warehouse storage could provide the bag on credit to the farmer in exchange for keeping the maize as collateral in a warehouse. The farmer can then repay the loan when the maize is sold. The lender's risk is reduced because this entity holds the maize until it is sold. This model is unproven but it follows the principle of warehouse receipt systems, where farmers receive credit or payment once the produce arrives at the warehouse, i.e. they do not have to wait until the trader has been paid for the produce. However, this would require farmers to give up control over their assets, and it implies additional storage costs for the warehousing entity.

5. Business case: tomato transport in Nigeria

5.1 Context

Tomatoes play an important role in the Nigerian economy, both in terms of production and consumption. In 2015, Nigeria produced 1.8 million metric tons of tomatoes, making Nigeria the second biggest producer in Africa and the fourteenth globally (GEMS4 2017). Most tomato producers are small-scale farmers with small areas under production.

Tomatoes are an important source of vitamins A and C and are the most commonly used vegetable in rural diets (Coffey International development 2014). Although Nigeria is a large producer, the country imports significant volumes (valued at USD 360 million in 2015). The need for imports is largely due to the severe seasonal variation of tomato production. There is little or zero local production between March and July, while overproduction in other months means that farmers often do not bother to harvest some tomatoes during gluts because of plummeting prices.

In addition to significant seasonal variation, tomato markets are greatly affected by regional differences in production and consumption. The largest volume of production comes from northern Nigeria, while the biggest demand centres are in southern Nigeria. Table 9 shows production and consumption for different states. Regional differences in production and consumption, particularly between northern and southern regions, create the need for tomatoes to be transported great distances, typically along the Lakaji Corridor (Figure 8).

Table 9: Production and consumption of tomatoes by region in Nigeria (thousands of tons per year)

	Northern	Northeast	Central	Eastern	Southwest	Southeast
Production	716	66	146	32	232	245
Consumption	415	91	107	56	341	417
Difference	301	-25	39	-24	-109	-172

Source: Coffey international development 2013.

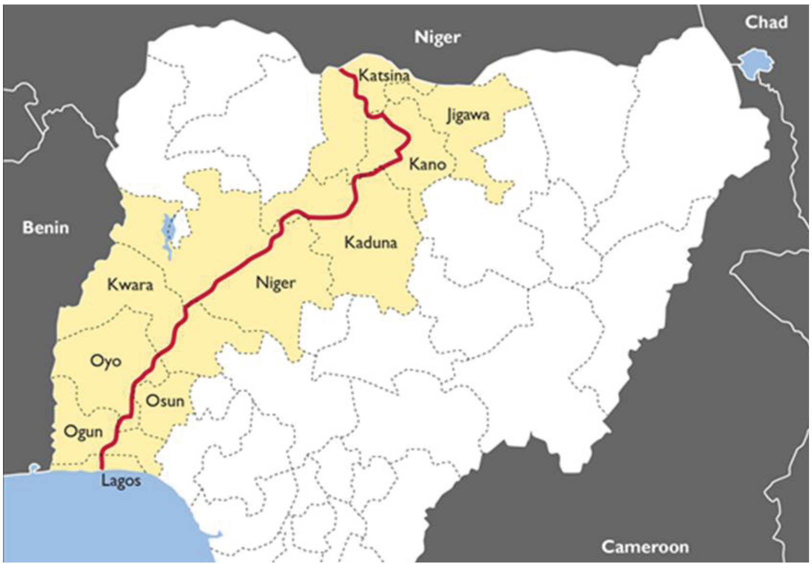


Figure 8: Lakaji Corridor.
Source: USAID 2013.

The Lakaji Corridor is 1,225 kilometres long and, in addition to transporting tomatoes, serves as a critical transportation route connecting the interior of the country with international markets. The journey takes between one and three days.

Tomatoes pass through many hands along this corridor. Farmers typically sell to local middlemen, who aggregate production and sell to traders. Traders make the trip to Lagos, where they sell to either wholesalers or directly to retailers. There are many markets in Lagos, but the largest is the Mile 12 market. Payment agreements between different actors vary, but it is not uncommon that farmers and middlemen in northern Nigeria are not paid until the traders return from Lagos on the next trip, after the tomatoes have been sold.

5.2 Reducing losses in the supply chain

Losses in the tomato supply chain are significant and occur at many stages. It is difficult to confidently estimate total losses, but losses could be as large as 86% of total production (Enclude and JMSF Agribusiness 2018). An estimated 25% of tomatoes are lost in harvesting or left on the vine due to low prices during peak season. Another 10% of losses occur at local collection centres before tomatoes are transported south. The largest losses—an estimated 41%—occur during transportation. Finally, 10% loss occurs at the retail market.

Recognizing the negative impacts of these losses on farmers and other small enterprises, a number of donor-supported programs have intervened to attempt to reduce losses in the tomato supply chain. The World Bank and the Department for International Development (DFID) supported the Growth and Employment in States (GEMS) program that included introduction of good-handling practices for tomatoes. The Rockefeller Foundation supported PYXERA Global that introduced tomato drying technologies and practices. Via its Global Alliance for Improved Nutrition (GAIN) program, the United States Agency for International Development (USAID) supported loss-reduction measures, including via plastic crates. The Multi-Donor Trust Fund for Sustainable Logistics (MDTL-SL), administered by the World Bank, also supported the team of Agrofair, the Netherlands and the International Fertilizer Development Center (IFDC), Nigeria to carry out participatory and practical research in 'living lab' settings with farmers, wholesalers, transporters and retailers to reduce post-harvest losses in tomato, introducing plastic crates and improving sun-drying through using raised platforms. Wageningen University & Research conducted impact monitoring with this project.

The majority of losses occurs during the transportation segment of the supply chain, meaning that addressing transportation losses could be most impactful. Amongst other measures, the use of plastic crates has large potential to reduce transportation losses. In most cases, tomatoes are transported in raffia baskets that hold approximately 50 kg of tomatoes (Figure 9). Baskets are stacked on top of one another, crushing tomatoes at the bottom. In comparison, plastic crates (see also Figure 9) bears the weight of other crates, reducing losses of tomatoes to as low as 5% (compared to 41% with baskets).

Figure 9: Raffia baskets versus plastic crates.

Photo credits: GEMS4 2017, Coffey International development 2014.

5.3 Costs and benefits of plastic crate use

5.3.1 Trader costs and benefits

The financial costs and benefits of introducing plastic crates are distributed across the supply chain from farmer to retailer. As mentioned above, in some cases farmers' payments are a portion of the sales the trader makes in Lagos, meaning that farmers would capture some of the financial benefits. However, without more information it is impossible to estimate the portion captured by each actor in the supply chain. For purposes of analysis, this report considers only the costs and benefits from the perspective of the trader, but recognizes that some costs and benefits may be passed to other actors.

There are many financial implications for substituting raffia baskets with plastic crates. Plastic crates cost between USD 7 (2,500 Naira) and USD 11.2 (4,000 Naira), while baskets cost only USD 1.12 (400 Naira). However, plastic crates last up to three years, while baskets last only one trip. Tomatoes in baskets can be packed more closely, increasing the volume of tomatoes per trader trip. However, because of significantly reduced transportation losses (41% versus 5%), the volume of tomatoes delivered to markets in Lagos would be substantially more with crates. (Ogundele 2017). Expected changes in monthly revenues, investments, and costs of goods sold are presented in Table 10. The authors assume that a trader is making four return trips per month to Lagos with a truck that has a 700-crate / 450-basket capacity. One crate holds 25 kg of tomatoes while one basket holds 50 kg. The authors assumed that tomatoes are purchased in northern Nigeria for USD 0.06 (20 Naira) per kg and sold for USD 0.22 (80 Naira) per kg in Lagos (Ogundele 2017).

Switching from baskets to crates also has implications for the return trip from Lagos to northern Nigeria. Baskets are discarded in Lagos, meaning that the truck has full capacity to take other goods north when it returns. Crates must be returned. They can be stacked on top of one another, meaning that about half of the volume of the truck is lost to returning crates. The value of goods being sold on the return trip is less than that of tomatoes. For the purpose of this analysis, the authors assumed that volume lost to returning crates results in a 25% reduction in revenues on the return trip. This number is highly variable, depending on the goods transported from Lagos to northern Nigeria. The authors assumed that tomatoes are only transported during seven months of the year and that the crates are unused during the other five months (Ogundele 2017).

Using modelled results, switching from baskets to crates appears to be a good investment. A significant upfront investment is recouped in approximately four months. Even though a truck filled with crates holds fewer tomatoes, many more tomatoes are delivered with quality that can be sold in Lagos. This increase in revenues is partially offset by the lost revenues during the return trip. The profitability of the investment is primarily derived from cost savings: by decreasing the cost of goods (purchase of tomato from the farmer) and by eliminating the need to buy new baskets for every trip. The investment is profitable, with a monthly IRR of 34% over seven months.

However, it is important to emphasize that the assumptions underlying these financial figures are highly uncertain. Two variables that have a significant impact on the profitability of the model are the assumed losses in tomatoes with baskets (and that severely damaged tomatoes cannot be sold for any value) and the effect that returning to the North with empty crates has on lost revenues. Furthermore, the business case does not

Table 10: Change in costs and revenues from switching from baskets to crates (USD)

Month	0	1	2	3	4	5	6	7
Increase in revenues	0	28	28	28	28	28	28	28
Increase in costs	5,376	-1,691	-2,195	-2,195	-2,195	-2,195	-2,195	-2,195
Net difference	-5,376	1,719	2,223	2,223	2,223	2,223	2,223	2,223

Source: Authors' calculations based on Ogundele 2017.

consider the time that crates will spend unused by traders, during harvest, at aggregation points, and at retail markets. The actual number of crates needed may be 4–5 times the number used by a trader at any one point.

5.3.2 GHG emissions reduction

The emission intensity of rural tomato production is the lowest of the three cases. Emissions per ton of tomato produced are calculated to be 0.1 tCO_2e. The reduction in losses and associated GHG reductions are shown in Table 11.

5.4 Barriers to scaling up

Compared to the other two cases, switching from baskets to crates is less well developed in terms of its commercial application. With a few small exceptions, the adoption of crates has been highly subsidized by donor support. There are three main barriers to commercial adoption of the crates.

Uncertain profitability of the business model. As discussed above, the assumptions underlying the expected cash flows have high uncertainty, and small changes in certain variables could undermine the profitability of the investment. More evidence is needed to determine costs, benefits, and other underlying assumptions.

Moreover, while the investment of crates appears sound, the means of rolling out crates on a commercial basis needs to be developed. It is not yet clear, for example, whether farmers or traders should buy the crates, or whether it would make more sense to support businesses that are renting the crates.

Manufacturing capacity. There are companies that manufacture crates, but they will only take orders of 10,000 or above. Given the small-scale enterprises of many actors in the supply chain, few businesses could place such a large order. Traders, for example, would need 700 crates for one truck load. However, an estimated 6 million crates are needed to transport tomatoes in the country, so the hypothetical demand is more than sufficient.

Tracking crates. In order to improve handling of tomatoes, crates need to pass through many hands in the tomato supply chain. Proper incentives (e.g. deposits) need to be established in order to ensure that the owner of the crate can ensure return of crates. Additionally, use of technologies such as bar codes on crates could make tracking easier.

Access to finance. The upfront investment of purchasing crates is high for small businesses and thus a significant barrier to adoption of crates. The immediate return on investment and relatively short payback period makes the investment a good case for financing from local banks, in theory. However, the actors who would be purchasing crates—either farmers or traders—are perceived to be risky by banks and have difficulty in accessing even short-term loans from local banks. Interest rates are generally quite high for agribusiness clients in the country.

5.5 Solutions

Prove the business case and facilitate financing. Donor-funded programs have provided important support for adopting crates. To transition to a commercial model, data collected during donor programs should be made available and studied to better understand the business case, including the most important financial sensitivities. Reliable cash flow models can give financial institutions more confidence to lend for the activity. The distribution of benefits from crate adoption needs to be understood in order to understand actors' incentives and how crates can be returned to their owner. Reducing lenders' risk for investing in crates can also facilitate their uptake. The Nigeria Incentive-Based Risk Sharing System for Agricultural Lending (NIRSAL) would be critical for such an effort.

Support for crate rental companies. Given the economies of scale needed to manufacture crates, widespread adoption of crates is unlikely to happen without developing companies whose business model is based on renting crates or other schemes that enable widespread use of crates with small-scale payments. Rental companies are likely to be start-ups or recently established companies that, under normal conditions, would require significant financial investment and business management skills.

Improve the enabling environment. Legislation is being considered that would regulate 12 Mile market, where most tomatoes are sold in Lagos. Legislation includes introducing handling and quality standards, such as the mandatory use of plastic crates in the trade of fresh fruits and vegetables. Such regulation could have a quick and dramatic effect on the use of crates.

Table 11: GHG benefits from reducing tomato losses

Loss reduced per crate over its lifetime	GHGs emitted at national level associated with losses	Marginal abatement cost
756 kg	0.05 MtCO_2e	-USD 85 per tCO_2e

Source: Authors' calculations using EX-ACT Tool. Note: the negative marginal abatement cost means that the revenues associated with the measure are greater than the costs after applying an appropriate discount rate.

6. Discussion and recommendations

The three supply chains and associated FLW-reduction measures examined in this study reflect measures focusing on food losses (rather than waste) in developing countries. The dairy measures in Kenya are larger scale and appropriate at the cooperative level. The two dairy cases have higher upfront costs and longer break-even periods, implying a need for longer term financing. In contrast, crates in Nigeria and bags in Tanzania have relatively low upfront costs and seasonal break-even periods. All measures are profitable under the assumptions of the study.

The GHG return on investment is highest for the two dairy measures. Given the high emission intensity of dairy production in Kenya, there is significant potential to reduce national emission intensity with the two proposed measures, in which the percentage reduction in emission intensity is equivalent to the percentage reduction in FLW. Introducing crates in the tomato supply chain in Nigeria has relatively low potential to reduce GHGs nationally, primarily because of the low GHG intensity of tomato production. The GHG efficiency of the investment is lower than in the dairy cases. Finally, introducing hermetic bags in the maize value chain has the lowest impact per unit of the three interventions presented in this report. However, given the large potential to upscale bags across the country, the emission-reduction impact can still be substantial.

Table 12: Summary of FLW-reduction cases

Measure	Annual food losses reduced	Break-even period	IRR	GHGs associated with losses (tCO_2e)
Dairy in Kenya				
Cooler	52,560 litres per cooler or 6% reduction	2 years	303% after five years (annual)	273
Extension services	65,610 litres per extension team or 4.5% reduction	1 year	72% after two years (annual)	341
Tomatoes in Nigeria				
Crate	252 kg per crate or 36% reduction	4 months	34% after three years (monthly)	0.02
Maize in Tanzania				
Hermetic storage bag	14 kg per bag or 14% reduction	3–6 months	23% after three years (monthly)	0.02

Note: GHG reduction potential is proportionate to FLW reduction potential and does not reflect the embedded emissions of the intervention, i.e. the emissions of producing the cooler, crates, bags or providing services. A full life cycle analysis has not been done.

Based upon this study, a number of trends and recommendations have been defined.

Where investment has been made to develop business models, profitable FLW interventions have been identified. Agricultural supply chains in many countries face severe FLW. There are many low-tech, low-investment measures that can make significant impacts on reducing FLW and increasing returns for farmers. The cases studied in this report ranged from reducing losses by 4.5% to as high as 36%, all with technology that is available in the countries studied. Economically competitive technology is not the missing link: rather, the overall business and investment environment in a country is often the major hurdle.

The profitability of FLW business models do not rely only on the reduction of FLW for increasing revenues or decreasing costs. In many cases, there are synergies between the reduction of FLW, improved quality, increased prices for businesses, or other profitability incentives. Improved quality, safeguarding against price fluctuations, and guaranteeing delivery of higher quantity all can improve the profitability of FLW interventions.

The cases identified make the biggest climate change mitigation impact via reducing the emission intensity (i.e. tons CO_2e per ton of food consumed) rather than by reducing the absolute quantity of emissions. While some FLW reduction measures also reduce the absolute amount of emissions, especially in the dairy sector, emission intensity should be the focus of FLW reduction work. Given the increasing demand for food products, this is a critical means of mitigating global emissions.

Where a business model has been established, supporting businesses that profit from FLW-reduction measures may be the most effective means of scaling up. Even though an appropriate technology or product has been developed, there is still a lot of work to be done before it becomes widespread and used on a commercial basis. It is important to identify which actors in the supply chain are most appropriate to adopt the new product. Even once appropriate businesses have been created or identified, they still need significant support to roll out the new product. Investing in marketing strategies and business management skills can help to accelerate uptake of a FLW intervention.

Lack of access to finance is a primary barrier to investing in FLW interventions across the supply chains studied. Agriculture is already perceived as one of the riskiest sectors for lending in developing countries. Many FLW investments have payback periods that are challenging for farmers with immediate cash needs to adopt, and appropriate credit is difficult for farmers to access. Absorbing the credit risk of farmers related to FLW investments would contribute significantly to increasing uptake of FLW measures. Additionally, perceived credit risk is also related to the business and financial management skills of the investees, so increasing business management capacity in these businesses would increase adoption of FLW measures.

Donor support has played a key role in developing FLW interventions at initial stages. The Gates Foundation, the Rockefeller Foundation, USAID, UK-AID, the World Bank, and many others have invested in early stage development of technologies and products that reduce FLW. Hermetic bags for cereal storage and crates for tomato transportation are available because of years and decades of investment in these measures. This type of high-risk / non-commercial funding is key in the early stages of research, development, and deployment of new technologies.

Efforts in developed countries, such as ReFED, have been successful in promoting FLW-reduction measures by enabling the private sector to understand the economic benefits. In developing countries, FLW is more related to the production and farm-to-processor parts of the supply chain than in developed countries. Accordingly, the platform would need to consider different partners and approaches but could learn from ReFED's experiences. CCAFS or other actors could partner with ReFED to explore the feasibility of developing a similar platform or initiatives in CCAFS target countries.

The climate change mitigation potential was calculated using the EX-ACT Tool. While the EX-ACT Tool is useful to quickly compare supply chains, there is a high uncertainty related to using Tier 1 default values found in the tool. A more detailed supply chain life cycle analysis e.g. using the Gold Standard Scope 3 would be more accurate. The authors recommend expanding the analysis of emission benefits and investment opportunities by considering indirect GHG emission benefits related to land-saving and analysing the potential for scaling specific business cases at national or even global scale.

Poor regulatory or enabling environments are consistent barriers to scaling up FLW interventions. Health and safety and quality standards, in particular, can create conditions for FLW-reduction measures to succeed. In some cases, the proper regulatory framework exists but is not adequately enforced.

All measures are expected to benefit smallholder producers, either directly in the case of hermetic bags and dairy extension services, or indirectly in the case of tomato crates and dairy coolers. In terms of indirect benefits, the increase in revenues and profitability in the supply chain occur very close to the producer in the supply chain, and so it is reasonable to expect that producers capture some of these benefits. The exact portion of benefits captured by smallholders needs to be further studied. In the long run, while the interventions push the supply chains to be more market-oriented, there are few adverse impacts expected in terms of smallholders being disadvantaged.

It is also important to consider potential adverse environmental impacts of the proposed interventions. For example, when profitability is increased there is sometimes an incentive for producers to increase production and ultimately increase overall emissions. The greatest risk comes in the case of satellite coolers for dairy in Kenya. While some coolers are solar-powered, they can also use diesel fuel. In such cases, the benefits of reducing GHG intensity of milk production could be offset by the increase in use of diesel. In the other cases, there may be a small incentive to producers to increase dairy, tomato, or cereals production if production is more profitable as a result of the FLW intervention. However, this impact would likely be minimal. In general, the potential for other negative environmental or social equity impacts from adopting the proposed measures needs to be further assessed.

Business models for reducing FLW are not well understood at the level of specific interventions. Many studies that evaluate different FLW interventions do not consider the business case (e.g. investment costs and returns). The authors had a difficult time identifying cases in which reliable information was available. Because many FLW interventions are driven by donor or research interests rather than commercial concerns, the business cases are not yet developed.

More research is required on business models to understand where profits can be made on reducing FLW and which actors are best placed to implement interventions. Finally, additional business cases should focus on gender-specific business cases to address social justice and equity concerns.

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The carbon footprint of food loss and waste (FLW) is estimated to be up to 3.49 gigatons of carbon dioxide equivalent ($gtCO_2e$), representing up to 6–10% of total anthropogenic greenhouse gas emissions. Reducing FLW can reduce the emission intensity of agricultural production. Moreover, many FLW reduction measures are profitable thanks to increased revenues. This study examines the business case for reducing FLW by examining three supply chains in detail: tomatoes in Nigeria, dairy in Kenya, and cereals in Tanzania. The cases reveal key strategies that should inform other efforts to reduce FLW at scale.

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