10

Reducing Greenhouse Gas Emissions by Reducing Food Loss and Waste

Value Chain Interventions from Farmer to Fork

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Highlights

- Food loss and waste (FLW) strongly contribute to the climate impact of the food supply and impair food security.
- FLW and the associated climate impacts vary greatly among different types of adopted technology and value chain configurations. Solutions should be found per specific situation.
- FLW can be approached from a chain perspective; in many cases, reducing FLW at a certain chain stage is best achieved by interventions elsewhere along the chain.
- The Agro-Chain Greenhouse Gas Emissions (ACE) calculator supports the identification of FLW and greenhouse gas (GHG) emission hotspots along a chain, as well as estimating the net effects of interventions.
- FLW-reducing interventions mostly contribute to climate mitigations, as demonstrated for rice and various fruits and vegetables; however, some high-tech interventions may induce higher extra GHG emissions than can be mitigated by FLW reduction.

10.1 Introduction

Food loss and waste (FLW) are important contributors to food insecurity and have a considerable environmental impact by inducing extra crop production and post-harvest greenhouse gas (GHG) emissions. Emissions associated with FLW are responsible for 8–10 percent of anthropogenic GHG emissions, comparable to emissions from all global road transport (Guo et al., 2020; Lamb et al., 2021). Therefore, mitigating FLW and climate impact from food supply chains should be addressed coherently.

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Mitigating FLW is a global priority. This chapter largely focuses on food loss (FL), although mitigating food waste (FW) is also crucial (Box 10.4). The United Nations Sustainable Development Goal (SDG) 12.3 – the ambition to significantly reduce FL along production and supply chains by 2030 – is supported by an increasing number of public- and private-sector stakeholders. Such efforts, however, should recognise trade-offs with other sustainability indicators such as climate change.

Most FL-reducing interventions will not only lower environmental impacts per unit of product available for consumption but also induce extra emissions, for example, through energy, fuel, and materials used for packaging. Estimating these trade-offs – and selecting interventions with the most positive balance accordingly – is far from easy but essential to best contribute to multiple SDGs. Moreover, barriers to implementation, in particular limited accessibility and availability, are persistent and should be addressed to realise sustainable food system transformations.

An important first step in shrinking FL with positive SDG trade-offs is identifying where action is needed. This chapter addresses the main actions necessary to address this challenge and scale a broadly supported, sustainable transition towards reduced FL. We discuss identifying loss and waste hotspots and examples of FL-reducing interventions in their wider food-system context. We discuss the required enabling environment and potential economic and policy voids, the relevant food system considerations needed for transformation, and the main policy implications.

10.2 Hotspot Analysis of Food Loss and Waste and Associated Greenhouse Gas Emissions

To design effective intervention strategies to reduce FL and associated GHG emissions, we need to identify and prioritise 'hotspot' regions, products, and supply chain stages. To set the right priorities, we assessed the worldwide hotspots of FLW and FLW-induced GHG emissions (Guo et al., 2020).[1] Our global hotspot analysis shows that in 2018, 29 percent of all food produced was lost or wasted. By volume, perishable fruits and vegetables account for almost half of the total FLW (Figure 10.1). Other items with high FLW volumes are roots and tubers, oil crops, and rice. In terms of FLW-associated GHG emissions, beef products are a major hotspot, despite not being an FLW hotspot in terms of volume. This reality reflects the high GHG-emission factors related to animal-based products, particularly beef.

Hotspots differ regionally; for example, in the two regions of Sub-Saharan Africa (SSA), and South and Southeast Asia, FL from post-harvest handling and distribution are higher than FW during the consumption stage. This situation

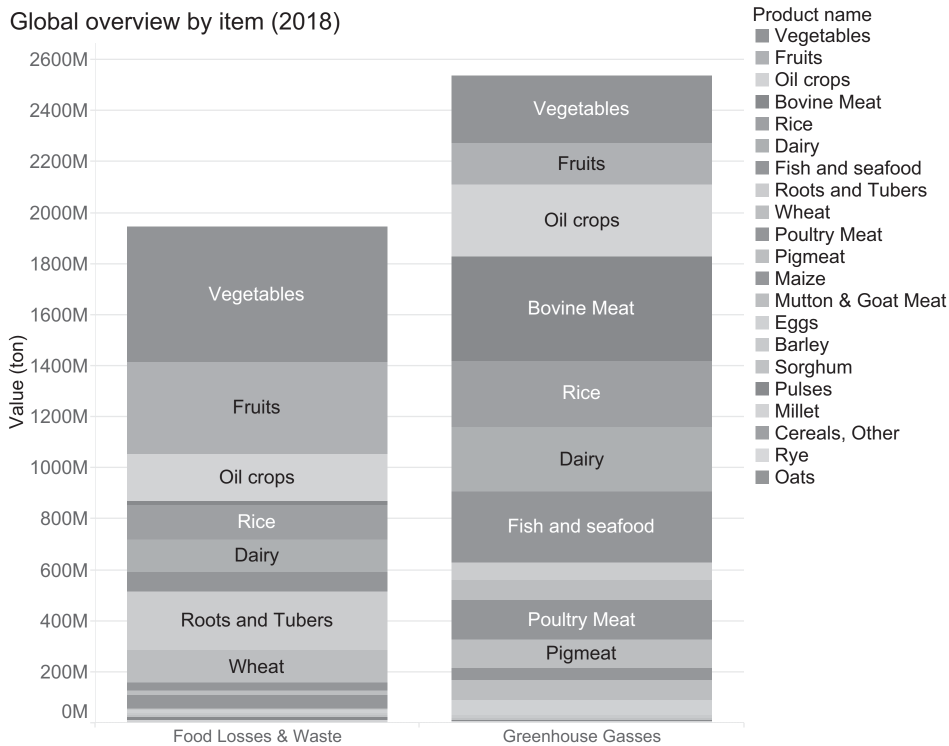

Figure 10.1 A global overview of food loss and waste in raw product equivalent, and associated greenhouse gas emissions in 2018

reflects the comparably poor post-harvest management and lack of infrastructure and technologies in those regions. Moreover, food is relatively expensive in developing countries compared to people's incomes, resulting in low consumer-level FW.

For SSA, roots and tubers are the largest hotspot for FLW and associated GHG emissions, whereas in South and Southeast Asia the hotspots are oil crops and rice. Losses mainly occur during harvesting, storage, and handling due to poor conditions and practices in the upstream chain. For both regions, rice involves high losses and emissions at their upstream chain stages but also has substantial losses and emissions at the distribution and consumer stages. Compared to other staple crops such as maize and wheat, rice produces two to five times more field-related GHG emissions (Poore & Nemecek, 2018). Therefore, rice warrants particular attention in the context of the 2030 target to significantly reduce losses in major supply chains where both GHG emissions and losses are high.

Most rice is grown in developing countries with relatively low average yields and high post-harvest losses. The loss of edible grain is considerably lower with

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Box 10.1

Case Study: Rice Losses in Smallholder Farm Rice Supply Chains in Sub-Saharan Africa

Interventions on or near the farm – as a major upstream hotspot in most food chains – can have a major impact on overall FL and GHG emissions. However, including smallholder farmers in efforts to mitigate the climate impact of food supply chains in low- and middle-income countries can be a considerable challenge. Recent research into attainable intervention strategies for smallholder farmers shows the benefit of productivity-enhancing technology for farmers' incomes as well as a range of other food system outcomes, including environmental sustainability, food availability, and the socio-economic development of rural communities.

In a controlled experiment on smallholder rice farms in Nigeria, we measured the impact of mechanising farm activities (Castelein et al., 2021) (Figure 10.2). Results showed that switching to mechanised harvesting and threshing reduces harvest paddy losses from 9.6 percent to 0.9 percent, and increases threshing efficiency from 31.1 percent to 33.1 percent. An FL reduction – here defined as loss of the edible part of the crop – of almost one tonne (920 kg) can be achieved per farmer per harvest. After accounting for equipment costs, there is an associated income boost through yield increases and labour savings of approximately 16 percent, or US$400 (Table 10.1).

Mechanisation results in a net reduction of GHGs by 1 696 kilograms of carbon dioxide equivalent per hectare, even after accounting for emissions from the machinery itself. Scaling this impact to all rice farmers in Nigeria would reduce GHG emissions by 5.4 megatonnes of carbon dioxide equivalent. This case study shows how efficiently mechanisation can lessen environmental impact and FL, while increasing food production and farmer income.

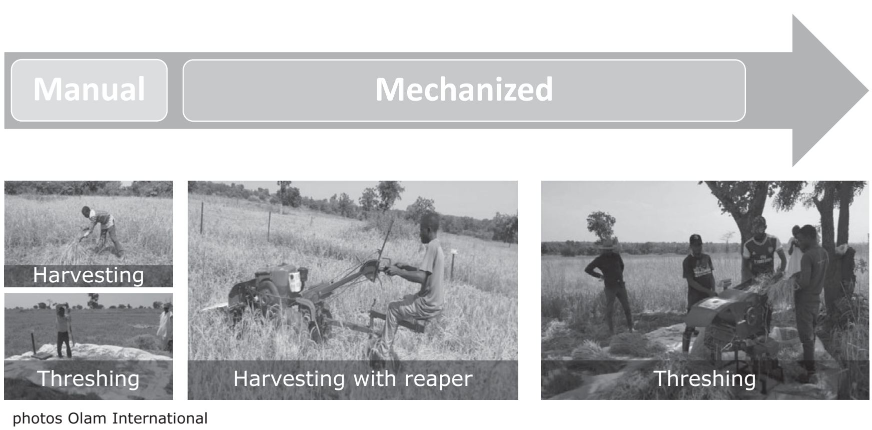

Figure 10.2 From manual to mechanised practices on Nigerian rice farms

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Box 10.1 (cont.)

Table 10.1. *Impact of different intervention scenarios in smallholder rice farming*

Criteria	Baseline: Manual harvesting threshing	Scenario 1: Shift baseline to mechanised harvesting	Scenario 2: Shift baseline to mechanised threshing	Scenario 3: Mechanised harvesting and threshing
Loss reduction and profit increase ha^{-1} $year^{-1}$	-	299 kg US$126	180 kg US$75	479 kg US$202
Loss reduction and profit increase per farmer, olam $year^{-1}$ (1.92 ha)	-	575 kg US$243	346 kg US$146	921 kg US$389
Costs of buying machine	-	US$2 050 reaper	US$875 thresher	US$2 925
Labour hours saved ha^{-1} $year^{-1}$	-	144	62	206
GHG per kg produced paddy rice	4.4	4	4.1	3.7
Climate impact of mechanisation (emissions avoided in kg CO_2eq)				
Ha^{-1} $year^{-1}$	-	1 042	716	1 696

mechanisation. Retaining more grain results in overall lower emissions per unit of product, and, generally speaking, the value of these avoided losses covers the economic expense of mechanisation (Castelein et al., 2021; Gummert et al., 2020; Nguyen-Van-Hung et al., 2018). Likewise, plant breeding for high-yielding, short-duration, and stress-tolerant varieties is an investment in mitigation, alongside agronomic management interventions, despite not often being construed as such (Ortiz-Monasterio et al., 2010). These interventions provide considerable potential to improve food security and farmer livelihoods while reducing rice's current carbon footprint (Box 10.1).

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10.3 Highlights of Other Case Studies

Potato Value Chain in SSA*:* In the smallholder potato value chain in Kenya, we evaluated farm-level interventions and their effect on the yields, losses along the chain, GHG emissions per unit food supplied to consumers, and the business case for farmers (Soethoudt & Castelein, 2021). Results show that mechanisation, adopting certified or clean seeds, and appropriate fertiliser and crop protection can reduce the yield gap and FL by 71 percent and GHG emissions per unit of marketed food by 51 percent, that is, the net effect of all interventions. Farmer income almost quadrupled. Mechanisation in particular significantly increases the yield per hectare and reduces crop damage – resulting in further rejections along the chain – even while inputs per hectare remain the same.

Export Chain for Dragon Fruit from Vietnam to Europe*:* 'Small' tropical fruit categories like dragon fruit are exported to other continents by air. With increasing volumes, however, alternative modalities with reduced GHG emissions are required, specifically reefer container transport. With the fruit collection system, however, the lengthy transportation phase results in high losses in the transportation and distribution phases. This not only leads to considerable losses but also substantial loss-associated GHG emissions. A third scenario that combines reefer containers for intercontinental transport with quick post-harvest refrigeration was identified as the best solution for FLW and GHG reduction (Table 10.2) (Axmann et al., 2021).

Increasing the Shelf Life of Cut Vegetables by Lowering the Cooling Temperatures*:* Through lowering the cooling temperature, the shelf life of cut vegetables is extended, thereby reducing FLW in retail (Broeze et al., 2019; see also Box 10.4). This results in less loss-associated GHG emissions but at the cost of additional energy use due to deeper cooling as well as a slightly extended

Table 10.2. *Food loss and waste and greenhouse gas emission results for different scenarios for transporting dragon fruit from Vietnam to Europe*

Scenario	Total losses along the chain (%)	Total GHG emissions per kilogram of fruit distributed (kg CO_2eq kg^{-1})
Traditional collection chain + air transport	15	26
Traditional collection chain + reefer container sea transport	44	24
Cooling in collection chain + reefer container sea transport	13	15

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Table 10.3. *Food loss and waste and greenhouse gas emission results for different cooling temperatures for cut vegetables. GHG emissions are quantified as kg CO_2eq. per kg vegetable sold in retail.*

Scenario	Total losses along the chain (%)	Total GHG emissions (kg CO_2eq per kg vegetable sold in retail)
Reference: Storage at 7°C	11.8	0.53
Reduced storage temperature: 4°C	9.4	0.55

average shelf period. One case study seemingly shows a negative trade-off between FLW reduction and GHG emissions reduction (Table 10.3).

10.4 A Generic Approach for Analysing Food Loss and Waste and the Climate Impact of Reduction Interventions

The above case studies illustrate that FLW often has positive trade-offs on food supply climate impact. However, the last example demonstrates that negative trade-offs may also occur. The significance of the trade-offs will mainly depend on specific conditions of the case study, that is, the actual crop GHG intensity in the particular situation, specific post-harvest operations, and level of FLW reduction.

Such analyses are mainly facilitated by tools that identify hotspots and support analysis of the effects of FLW-reducing interventions on climate. This will aid the decision-making process for both the private sector and policymakers. Such decision-support tools need to comprehensively show emissions across the chain so that decisions can be made with accurate, complete information and contribute to progress towards a food-secure, climate-conscious future. Two such tools – developed by this chapter's authors – include the Agro-Chain GHG Emissions (ACE) calculator and a Carbon Foot (CF)-rice production calculator (Boxes 10.2 and 10.3).

10.5 Food System Challenges

The rice case study raises the question of why farmers in SSA still primarily produce with manual labour and inferior inputs when the positive business case for other practices is clearly in place, with a relatively short time to impact (Daum & Birner, 2020). The case study findings highlight that the upfront costs are prohibitive to farmers, indicating that technology alone is not a sufficient solution; we must consider the food-system context in which the farmers operate, and how the availability and accessibility issues regarding inputs and equipment can be addressed.

Box 10.2

The Agro-Chain Greenhouse Gas Emissions Calculator: Assessing Agro-Chain Greenhouse Gas Emissions

In GHG accounting of food supply chains, losses in production and along the entire post-harvest chain must be addressed comprehensively, in order to assess trade-offs between FL and GHG emissions. For that the Agro-Chain GHG Emissions (ACE) calculator[1] combines emissions and losses per chain stage from production to the consumer to estimate total GHG emissions per unit of sold product, as well as FL and GHG emission hotspots along the chain (Figure 10.3). Since the calculator is fitted with average crop GHG intensity data and FL estimates per chain stage specified for seven global regions and commodity groups, estimates can be made with limited primary data (Porter et al., 2016). When available, data from direct measurements, expert estimates, or reference literature can make estimates more specific. Technology-specific data can be inserted for comparing different scenarios.

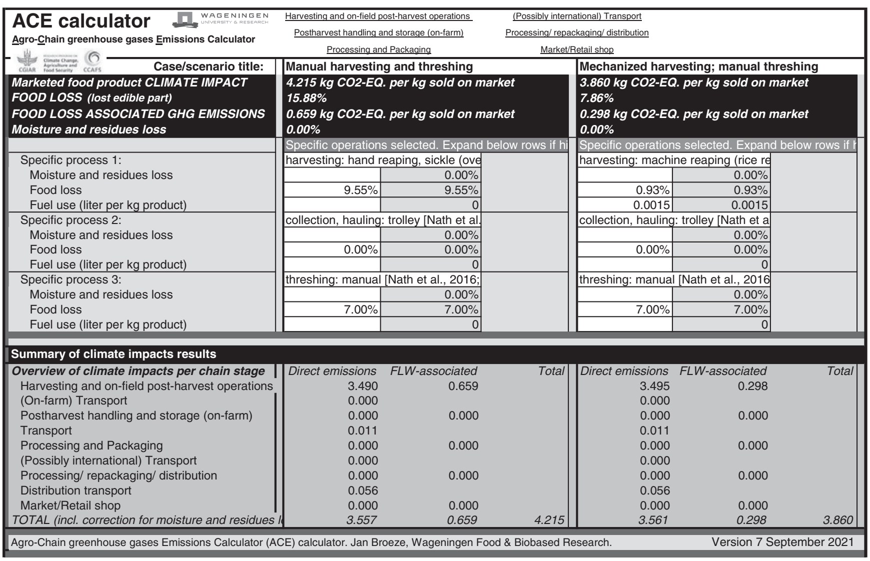

Figure 10.3 Part of the Agro-Chain Greenhouse Gas Emissions calculator user-interface for rice case comparison of technology scenarios [1] https://ccafs.cgiar.org/agro-chain-greenhouse-gas-emissions-acge-calculator

The evidence of lagging mechanisation in SSA highlights that incentives, financing, business models, capabilities, and chain arrangements are important factors in accessing and successfully implementing technology. Technology in itself is rarely a ready-made solution, but a more comprehensive systemic

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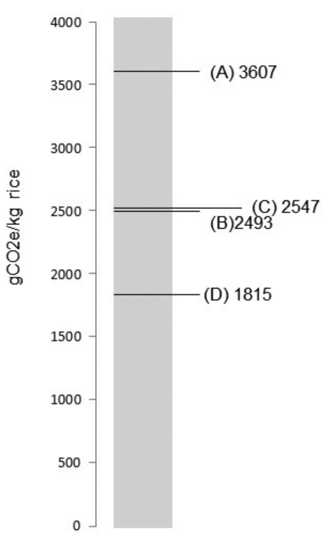
Box 10.3

Carbon Footprint-Rice Production (CF-Rice): An Emissions Calculator for Rice Production

CF-Rice is a new emissions calculator that accounts for different field management practices, production technologies, and post-harvest practices along the rice value chain to provide a comprehensive product-scaled carbon footprint output. Users can compare different scenarios with data from scientific literature to highlight points along the chain where interventions would deliver the most emission-reduction impact, including those from FLW. Alternatively, users can add data from their own operations to tailor results to specific conditions.

Figure 10.4 shows the product-scaled carbon footprint for four scenarios in Southeast Asian rice production: (A) lower yield of four tonnes per hectare with traditional practices, that is, continuous flooding, manual harvesting, sun drying, and farmer storage; (B) higher potential yields of six tonnes per hectare from improved varieties without management changes; (C) improved yields of six tonnes per hectare with conditions the same as scenario B plus improved harvest and post-harvest techniques, that is, continuous flooding, mechanised harvesting and drying, and hermetic storage; and (D) improved yields of six tonnes per hectare with conditions the same as scenario C plus the application of alternate wetting and drying (AWD) during



Management	A	B	C	D
Segments and Product				
Cultivation	3189	2126	2027	1295
Harvest & Post harvest	418	367	520	520
Carbon footprint of product (gCo2e/g rice)	3607	2493	2547	1815
Stage-specific for Cultivation				
Crop establishment	206	138	131	131
Water management	2561	1707	1628	895
Fertilizer application	287	191	183	183
Equipment operation	134	89	85	85
Stage-specific for Harvest and Post-harvest				
Harvest	37	24	23	23
Straw mangement	117	78	74	74
Drying	0	0	168	168
Storing	24	24	16	16
Milling	200	200	199	199
Packaging	2	2	2	2
Transport	38	38	38	38

Figure 10.4 Example output of CF-Rice, comparing the carbon footprint of four rice production scenarios

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Box 10.3 (cont.)

production. Reaching yield potential through improved varieties has a mitigation benefit of 31 percent, switching from scenario A to B. Although there is significant FL reduction from switching from scenario B to C, the emissions mitigation is negligible at under 2 percent. This is mainly a result of lessening emissions by saving food, while balancing increased emissions from mechanisation. In scenario D, the application of AWD, with improved varieties and better harvesting and post-harvesting techniques, has the most mitigation impact at 50 percent.

approach – including the creation of the appropriate capabilities, arrangements, and supporting markets and institutions – is needed for an effective transition. The success of technical solutions depends on adequate business models and chain arrangements in which all chain actors benefit.

Interventions with a positive business case still often encounter difficulty in accessing finance, especially interventions that require systemic changes. We identify three types of arrangements that can ensure access to finance. Needless to say, the following financial arrangements should be combined with capacity development.

1. While market-based financial services are often absent in rural communities, with the right conditions and supporting policy, they can exploit the untapped potential of smallholder mechanisation.
2. Farmer cooperatives can be a vehicle for collective procurement or for organising a sufficiently large market for rental equipment.
3. Financial support of smallholder farmers from larger buyers or input suppliers can assist in the upgrading of farmer practices.

Losses often arise elsewhere along the chain, outside of where the causes originate. Urbanisation and changing consumption patterns with informal chain arrangements result in increasing disconnection between producers and consumers, where demands from the consumer are not recognised by producers. Shrinking losses in a certain part of the chain through actions elsewhere in the chain will require collaboration, transparency, and chain–actor coordination.

10.6 Way Forward

By 2030, SDG Target 12.3 aims to halve FL. To reach that goal, loss-reducing interventions are critical. Besides cutting FL, most interventions will also mitigate food-supply GHG emissions. Understanding the effectiveness and trade-offs of such interventions is essential for FLW reduction decision-making and policy. Based on the experience in the case studies presented above, we recommend the following actions:

- Identify FLW and loss-related GHG emission hotspots and priorities. For policy-makers, this step occurs at the country or region level; for chain actors, it occurs along the chain.
- Identify hotspots and priorities per product type or product category.
- Distinguish different chain stages: harvesting, storage and handling, processing, food distribution, and, optionally, the consumption phase.
- Prioritise hotspots through the following actions:
  - Select hotspots with the highest loss volumes or for which interventions are available.
  - Compare FLW with various production practices, in different supply chain configurations, or with alternative technology or supply chain management practices.
  - Identify promising interventions based on an inventory of technology or management methods used in other situations, on a literature scan, or using other methodologies.
  - Estimate the interventions' effects on FLW along the supply chain.
  - Estimate the interventions' trade-off for climate impact, for instance through CF-Rice and/or ACE.
  - Narrow down the list of interventions to those that contribute significantly to FLW or GHG emissions reduction.
  - Estimate the business case for a realistic implementation model.
  - Examine how the intervention(s) can fit in the food system context; address the involvement of stakeholders and distribution of costs and benefits for actors along the chain; identify leverage points to stimulate actual implementation and success.
  - Develop a business model for the intervention.

Ideally, the focus will be on climate-positive loss-reduction interventions related to food products that are hotspots for FL and GHG equivalents. Globally, these are fruits and vegetables, rice, oil crops, and animal products. For most products, most emissions are related to agricultural production, meaning interventions in this sector can create a large impact. Any loss along the value chain induces extra production, however, which also requires consideration. In the case of smallholder farmer systems in low- and middle-income countries, the availability, accessibility, and longevity of FL-reducing interventions are significant barriers to transformation and can be addressed systematically.

This chapter provides a perspective on the requirements to foster lasting change: essentially, the right technology, supported by the right capabilities, financing options, and institutional arrangements. The case studies show that while technology does not have to be sophisticated, it needs to be available, accessible, and context-suitable. Currently, significant economic, institutional, and governance bottlenecks impede adoption. The availability and accessibility of technology and other interventions often hinder farmer adaptation, particularly in covering the upfront cost of equipment, inputs, and systems.

Financing options could be broadened, considering the wide impacts of FL reduction including implications for food security, resource use, and GHG emissions. Envisaged carbon credit schemes for shrinking FL-induced GHG emissions can motivate action. The right intervention, when effectively implemented, can positively impact all these outcomes, making FL reduction a major contributor to progress on multiple SDGs. Removing financial barriers to FL-reducing interventions helps include farmers in supply chain transformation, and leverage efforts towards more sustainable, equitable food systems.

Emissions calculator tools can support decision-making in food value chains. The two examples discussed in this chapter – the ACE calculator and CF-Rice – allow users to assess the carbon footprint impact of different intervention strategies and highlight points along the chain where interventions would be most impactful in reducing emissions, including those from FL. These tools integrate available statistical and research information into a comprehensive calculation model. This gives users the option to make the analysis more context-specific with data from their own operations. Through data from alternative chain configurations or with adapted data for comparing chain scenarios with different interventions, alternative configurations can be created.

On a global level, developed and emerging economies are responsible for the majority of FLW and associated GHG emissions. In low-income countries, however, FLW reduction relates directly to food and nutrition security and resource use efficiency. In line with the Paris Agreement, developed countries should therefore take the lead in improving climate mitigation and food security by cutting FLW. This effort should go along with financial support to less endowed, more vulnerable countries.

Box 10.4
Tackling Food Waste by Charlie Pye-Smith

In high-income countries, most food is wasted beyond the farm gate by households, manufacturers, the hospitality and food industry, and retailers (Steiner et al., 2020). Measured in calories, consumers account for around 20 percent of all FW, of which three-quarters comes from the quarter of the world's population living in Europe and the Americas. Steiner et al. (2020) outline a number of mechanisms to achieve the target of reducing FW by 50 percent by 2030. These include developing early warning systems and information management to match food supply with demand, using smart marketing and information platforms, optimising inventory movement in warehouse storage, and reducing waste-related costs along the value chain. They advocate introducing incentives to encourage manufacturers to supply smaller portions and adopt more efficient management of waste, for example by using it in anaerobic digesters and as compost rather than sending it to a landfill. They also support the creation of incentives that encourage companies to measure FLW.

There is a powerful business case for reducing FW, as illustrated by a nationwide initiative in the United Kingdom. Between 2007 and 2012, a basket of measures introduced by the private sector, local governments, community groups, and households led to a 21 percent reduction in household FW. Every £1 invested resulted in savings of £250. The waste reduction initiative was worth £6.5 billion of savings to households and £86 million of savings to local authorities over that five-year period. It decreased GHGs by 3.4 million tonnes per year, equivalent to taking 1.4 million passenger cars off the road. It also helped to save 1 billion m^3 of water.

An analysis of nearly 1 200 business sites involving 700 companies in 17 countries found that 99 percent of the sites showed a positive return on investment in waste management, with half boasting a 14-fold return. In other words, for every US$1 invested in FLW reduction, the average company made a return of US$14. This sort of evidence has convinced many companies to tackle FW.

One of the most successful companies to tackle FW has been the furniture retailer IKEA. Almost 1 billion people visit its 420 stores each year, some two-thirds of whom eat in its food outlets. In 2016, IKEA launched its Food is Precious initiative with the aim of reducing FW by 50 percent by 2020. Activities included using a smart scale system to monitor FW and appointing FW champions to motivate colleagues at work and at home. By 2019, the initiative had been implemented in half its stores, with many reducing FW by 50 percent or more. Indeed, IKEA experienced a 20 percent reduction in FW within just 12 weeks of launching the initiative.

Another company that has successfully reduced FW is Unilever. Its Future Foods initiative has adopted the target–measure–act approach recommended by the Champion 12.3 initiative, with the aim of cutting FLW in half by 2025. Among other things, it also involves making better use of waste products. In 2020, 19 percent of FW

Box 10.4 (cont.)

went to anaerobic digestion, 14 percent was used as compost, 26 percent was applied to the land as a fertiliser, and 37 percent was sent for incineration with energy recovery. None was sent to a landfill.

Many other companies and institutions have dramatically reduced their FW in recent years by adopting a variety of measures. For example, the Danish bioscience company Chr. Hansen has used food cultures to extend the shelf life of its yoghurt, reducing waste by 40 percent between 2016 and 2019. The Swedish restaurant company Max Burgers launched the world's first climate-positive menu in 2018. Less than 1 percent of food is now wasted in its kitchens, and its operations are powered entirely by renewable energy.

Awareness campaigns in school feeding programmes and institutions are also helping to lessen FW on a significant scale. For example, reducing waste, as well as malnutrition, is an integral part of the Brazilian School Feeding Programme, which supplies some 42 million children with one or more healthy and nutritious meals every day in 160 000 public schools. Awareness raising was also a central part of the 'Love Food Hate Waste' campaign, which led to a 21 percent reduction in FW in the United Kingdom between 2007 and 2012.

Notes

1 Following Porter et al. (2016) and the Food and Agriculture Organization of the United Nations FLW definition, in this research we counted FLW in raw product equivalent.

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