

2019
THE STATE OF
FOOD AND
AGRICULTURE
MOVING FORWARD ON FOOD
LOSS AND WASTE REDUCTION



Food and Agriculture Organization of the United Nations
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FOREWORD

I am heartened to see that the world is paying more attention to the issue of food loss and waste and is calling for more decisive action to address it. The growing awareness and increase in calls for action are rooted in the strong negative moral connotations associated with food loss and waste. These are partly based on the fact that losing food implies unnecessary pressure on the environment and the natural resources that have been used to produce it in the first place. It essentially means that land and water resources have been wasted, pollution created and greenhouse gases (GHGs) emitted to no purpose. I also frequently wonder how we can allow food to be thrown away when more than 820 million people in the world continue to go hungry every day.

International attention on the issue of food loss and waste is firmly reflected in the 2030 Agenda for Sustainable Development. Specifically, Target 12.3 of the Sustainable Development Goals (SDGs), which embody this agenda, calls for the halving by 2030 of per capita global food waste at the retail and consumer levels and the reduction of food losses along production and supply chains, including post-harvest losses. Many countries are already taking action to reduce food loss and waste, but the challenges ahead remain significant and we need to step up efforts. Furthermore, as this report argues, efforts to meet SDG Target 12.3 could contribute to meeting other SDG targets, not least that of achieving Zero Hunger, in line with the integrated nature of the 2030 Agenda.

However, as we strive to make progress towards reducing food loss and waste, we can only be truly effective if our efforts are informed by a solid understanding of the problem. Three dimensions need to be considered. Firstly, we need to know – as accurately as

possible – how much food is lost and wasted, as well as where and why. Secondly, we need to be clear about our underlying reasons or objectives for reducing food loss and waste – be they related to food security or the environment. Thirdly, we need to understand how food loss and waste, as well as the measures to reduce it, affect the objectives being pursued. This report sheds light on these three dimensions in order to help design more informed and better policies for food loss and waste reduction.

Concerning the first dimension, the surprising fact is how little we really know about how much food is lost or wasted, and where and why this happens. A broad estimate, prepared for FAO in 2011, suggested that around a third of the world's food was lost or wasted every year. This estimate is still widely cited due to a lack of information in this field, but it can only be considered as very rough. It is therefore in the process of being replaced by two indices, thanks to efforts by FAO and UN Environment to estimate more carefully and more precisely how much food is lost in production or in the supply chain before it reaches the retail level (through the Food Loss Index) or is subsequently wasted by consumers or retailers (through the Food Waste Index). Initial estimates made by FAO for the Food Loss Index, which I am pleased to release through this report, tell us that globally around 14 percent of the world's food is lost from production before reaching the retail level. Estimates for the Food Waste Index are under preparation by UN Environment and will complement the Food Loss Index to provide a better understanding of how much food is lost or wasted in the world. These indices will allow us to monitor progress towards SDG Target 12.3 over time, starting from a more solid baseline.

However, to intervene effectively we also need to know where in the food supply chain losses and

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waste are concentrated and the reasons why they occur. Evidence presented in this report shows that losses and waste tend to be higher for some specific commodity groups, although they can occur at all stages of the food supply chain to different degrees. However, what really struck me is the vast range in terms of percentages of food loss and waste for the same commodities and the same stages in the supply chain both within and across countries. This suggests that there is considerable potential to reduce food loss and waste where percentage losses are higher than in other places. However, it also shows that we cannot generalize about the occurrence of food loss and waste across food supply chains but must, on the contrary, identify critical loss points in specific supply chains as a crucial step in taking appropriate countermeasures.

Regarding the second dimension, although the SDGs include the reduction of food loss and waste as a target in its own right, we need to be clear about why we are pursuing it – or what is the underlying objective. Individual actors, from farmers and fishers right up to consumers, may have a private interest in reducing food loss or waste to increase their profits or income, their personal well-being or that of their families. However, this private incentive is not always strong since reducing food loss and waste may require investing money or time which, in the perception of these actors, could outweigh the benefits. There may also be barriers that prevent private actors from making these investments, e.g. credit constraints or a lack of information about options for reducing food loss and waste. On the other hand, there may be a stronger public interest in reducing food loss and waste because it contributes to other public objectives. This calls for public interventions in the form of investments or policies that create incentives

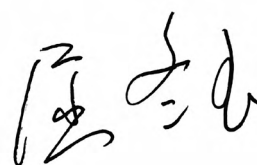
for private actors to reduce food loss and waste or remove the barriers that prevent them from doing so. The broad public objectives that this report considers are twofold: improving the food security situation of vulnerable groups and reducing the environmental footprint associated with food that is lost or wasted.

A key argument in this report is that the linkages between food loss and waste, on the one hand, and food security and environmental impacts, on the other, are complex and need to be thoroughly understood. Positive outcomes from reducing food loss and waste are far from guaranteed, and the impacts will differ according to where food loss and waste is reduced. It is exactly for this reason that policymakers need to be clear about the objectives they choose to pursue. Focusing on one objective will indeed have implications for where food loss and waste reductions can be most effective.

For instance, if the objective is to improve food security, reducing on-farm losses – particularly on small farms in low-income countries with high levels of food insecurity – is likely to have strong positive impacts. It may directly improve food security in the affected farm households and may also have positive effects in local areas, and even beyond, if more food becomes available. Reducing food loss and waste further along the food supply chain may improve food security for consumers, but farmers may actually be negatively affected if demand for their produce declines. On the other hand, while reducing consumer food waste in high-income countries with low levels of food insecurity may have some impact on vulnerable people locally through food collection and redistribution initiatives, the impact on the food insecure in distant low-income countries is likely to be negligible.

If the objectives for reducing food loss and waste are essentially environmental, the situation changes. In the case of GHGs, these accumulate throughout the supply chain. Therefore, cutting waste by consumers will have the biggest impact because food wasted at this stage represents a larger amount of embedded GHG emissions. In the case of land and water, the environmental footprint is tied mainly to the primary production phase. Therefore, reducing food loss and waste at any stage of the food supply chain can contribute to reducing overall land and water use at the global level. However, if you want to address local land and water scarcity, measures to reduce food loss are likely to be more effective if they occur at the farm level or at stages in the supply chain close to the farm level.

I invite you to read this report carefully as it examines the complex ways in which food loss and waste – and the measures taken to address it – affects food security and the environment. The report does not claim to have all the answers, particularly as it acknowledges the important information gaps that stand in the way of a comprehensive analysis. Among other things, the report attempts to highlight precisely where there is a need for a more thorough understanding of the issues, both through more and better data and improved and expanded analysis. It is my hope that it can make a contribution to the debate on how to address the problem of food loss and waste most effectively and in ways that actually make a difference in terms of improved food security and environmental sustainability, following the spirit of the 2030 Agenda.



Qu Dongyu
FAO Director-General

METHODOLOGY

The preparation of *The State of Food and Agriculture 2019* began with an inception workshop, held at FAO headquarters in Rome on 10 September 2018 and attended by members of a panel of external experts and FAO specialists. Following the workshop, an advisory group representing all relevant FAO technical units and chaired by the Deputy-Director of FAO's Agricultural Development Economics Division was formed to assist in the drafting process. At a seminar held on 17 October 2018, the research and writing team and the advisory group discussed the report's outline. The first three draft chapters were presented to the advisory group on 18 January 2019. Based on comments received from the advisory group, the team revised the draft. The first full draft was then presented to the advisory group and panel of external experts on 1 February and discussed at a second workshop held on 14–15 February. With inputs from that workshop, the report was revised and presented to the management team of FAO's Economic and Social Development Department. The revised draft was sent for comments to other FAO departments and to the FAO regional offices for Africa, Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, and the Near East and North Africa, as well as to external reviewers. Comments were incorporated in the final draft, which was reviewed by the Assistant Director-General of the Economic and Social Development Department, and then submitted to the Office of the FAO Director-General on 9 July 2019. In drafting the report, the research and writing team drew on background papers prepared by FAO and external experts.

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ACRONYMS AND ABBREVIATIONS

AGRIS	Agricultural Information Management Standards	HH	household
APEC	Asia-Pacific Economic Cooperation	IFAD	International Fund for Agricultural Development
APHLIS	African Postharvest Losses Information System	IFPRI	International Food Policy Research Institute
CO₂	carbon dioxide	IMF	International Monetary Fund
EBRD	European Bank for Reconstruction and Development	m³	cubic metre
EU	European Union	NGO	non-governmental organization
FAO	Food and Agriculture Organization of the United Nations	ReFED	Rethink Food Waste
FBS	Food Balance Sheet	SDG	Sustainable Development Goal
FIES	Food Insecurity Experience Scale	SUA	Supply Utilization Accounts
FLI	Food Loss Index	UK	United Kingdom of Great Britain and Northern Ireland
FLP	Food Loss Percentage	UN	United Nations
FLW	food loss and waste	UN Environment	United Nations Environment Programme
FWI	Food Waste Index	USD	United States dollar
GBP	pound sterling	USDA ERS	United States Department of Agriculture Economic Research Service
GDP	Gross Domestic Product	WFP	World Food Programme
GHG	greenhouse gas	WRAP	Waste and Resources Action Programme
ha	hectare	WRI	World Resources Institute

EXECUTIVE SUMMARY

FOOD LOSS AND WASTE – FRAMING THE ISSUES TO FACILITATE ACTION

Reducing food loss and waste is widely seen as an important way to reduce production costs and increase the efficiency of the food system, improve food security and nutrition, and contribute towards environmental sustainability. Growing attention to food loss and waste is reflected in the Sustainable Development Goals (SDGs). SDG Target 12.3 calls for *halving per capita global food waste at the retail and consumer levels and reducing food loss along production and supply chains (including post-harvest losses) by 2030*. Reducing food loss and waste also has the potential to contribute to other SDGs, including the Zero Hunger goal (SDG 2), which calls for an end to hunger, the achievement of food security and improved nutrition, and the promotion of sustainable agriculture. The expected positive environmental impacts from reducing food loss and waste would also affect, among others, SDG 6 (sustainable water management), SDG 13 (climate change), SDG 14 (marine resources), SDG 15 (terrestrial ecosystems, forestry, biodiversity), and many other SDGs.

While the reduction of food loss and waste appears as a clear and desirable objective, actual implementation is not simple and its complete elimination may not be realistic. This report acknowledges the need to reduce food loss and waste, presents new insights on what is known and what is not, and provides guidance on how to target interventions and policies depending on policymakers' objectives and the information available. Deciding on concrete actions, interventions or policies to reduce food loss and waste requires answers to a number of questions: In which locations and stages of the supply chain is food lost or wasted and to what extent? Why does food loss and waste occur? How can it be reduced? What are the costs involved? And, ultimately, who benefits from reducing food loss and waste, and who loses?

Responding to all these questions will require access to proper information.

When considering actions and policy options, the report argues that food loss and waste reduction should be seen as a way to achieve other objectives, notably improved efficiency in the food system, improved food security and nutrition, and improved environmental sustainability. How policymakers prioritize these different dimensions, and the information available on how food loss and waste affects them, will shape the most appropriate mix of interventions and policies to reduce food loss and waste.

KNOWING WHAT CONSTITUTES FOOD LOSS AND WASTE AND HOW TO MEASURE IT PRECEDES TAKING ACTION

The notion of food being lost or wasted is deceptively simple, but in practice there is no commonly agreed definition of food loss and waste. The various definitions often reflect the different problems that stakeholders or analysts focus on or associate with food loss and waste. Consequently, analysis of food loss and waste is hampered by this lack of a common definition. FAO has worked towards the harmonization of concepts related to food loss and waste, and the definitions adopted in this report are the result of a consensus reached in consultation with experts in this field. This report understands food loss and waste as the decrease in quantity or quality of food along the food supply chain. Empirically it considers **food losses** as occurring along the food supply chain from harvest/slaughter/catch up to, but not including, the retail level.

Food waste, on the other hand, occurs at the retail and consumption level. This definition also aligns with the distinction implicit in SDG Target 12.3. This report also asserts that, although there may be an economic loss, food diverted to other economic uses, such as animal feed, is not considered as quantitative food

loss or waste. Similarly, inedible parts are not considered as food loss or waste.

Food loss and waste has typically been measured in physical terms using tonnes as reporting units. Although useful for estimating environmental impacts, this measurement fails to account for the economic value of different commodities and can risk attributing a higher weight to low-value products just because they are heavier. When devising interventions and policies to reduce food loss and waste, it is important to account for the monetary costs and benefits of any reduction. The report acknowledges this by adopting a measure that accounts for the economic value of produce.

Agreeing on a consistent approach to monitor SDG Target 12.3 is an important step in framing the debate on food loss and waste and will provide guidance on where to intervene. Efforts are underway by FAO and the United Nations Environment Programme (UN Environment) to measure progress towards SDG Target 12.3 through two separate indices: the **Food Loss Index (FLI)** and the **Food Waste Index (FWI)**. This report releases the first estimates for the FLI, prepared by FAO, which indicates that globally – in terms of economic value – around 14 percent of food produced is lost from post-harvest up to, but not including, the retail level. For the FWI, covering retail and consumption, significant work has been carried out to prepare the methodological framework, but the first estimates are yet to be released by UN Environment.

VARIATIONS IN LEVELS OF FOOD LOSS AND WASTE THAT OCCUR ACROSS REGIONS, COMMODITIES AND SUPPLY CHAINS CAN PROVIDE PRELIMINARY GUIDANCE ON WHERE TO INTERVENE ...

To gain further insight into the location and extent of food loss and waste, FAO has also conducted a meta-analysis of existing studies

that measure food loss and waste in countries all over the world. It illustrates how food loss and waste varies across stages in the food supply chain, as well as between regions and commodity groups. The meta-analysis finds a wide range of values for percentage losses at each stage in the food supply chain. This highlights the need to measure losses carefully for specific value chains to identify concretely where significant losses occur, so as to better understand where to intervene. Generally levels of loss are higher for fruits and vegetables than for cereals and pulses. However, even for the latter, significant levels are found in sub-Saharan Africa and Eastern and South-Eastern Asia, while they are limited in Central and Southern Asia. Studies on waste at the consumer stage are confined to high-income countries; they indicate that waste levels are high for all types of food, but particularly for highly perishable foods such as animal products and fruits and vegetables.

Causes of food loss and waste differ widely along the food supply chain. Important causes of on-farm losses include inadequate harvesting time, climatic conditions, practices applied at harvest and handling, and challenges in marketing produce. Significant losses are caused by inadequate storage conditions as well as decisions made at earlier stages of the supply chain, which predispose products to a shorter shelf life. Adequate cold storage, in particular, can be crucial to prevent quantitative and qualitative food losses. During transportation, good physical infrastructure and efficient trade logistics are of key importance to prevent food losses. Processing and packaging can play a role in preserving foods, but losses can be caused by inadequate facilities as well as technical malfunction or human error.

The causes of food waste at the retail level are linked to limited shelf life, the need for food products to meet aesthetic standards in terms of colour, shape and size, and variability in demand. Consumer waste is often caused by poor purchase

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and meal planning, excess buying (influenced by over-large portioning and package sizes), confusion over labels (best before and use by) and poor in-home storing.

... BUT THIS GUIDANCE, WHICH IS BASED ON AVERAGE LOSSES AND WASTE, MAY NOT BE ENOUGH SINCE THERE ARE SIGNIFICANT VARIATIONS WITHIN REGIONS AND COMMODITY GROUPS

The meta-analysis finds a wide range of values for percentage losses even within the same region or commodity group, or at the same point on the supply chain. For example, in sub-Saharan Africa the observations on fruits and vegetables report on-farm losses ranging from 0 to 50 percent, a very broad range. An intervention to reduce these losses needs to target the upper end of this range to have maximum impact. Another example concerns losses of cereals and pulses in the processing and packaging phase in sub-Saharan Africa, which would appear to be low on average (the median loss is less than 5 percent), but where one quarter of the observations report between 10 and 20 percent losses. Looking only at average losses may not give an accurate picture regarding whether an intervention for a specific commodity would make sense, nor would it indicate where a potential intervention should take place.

The variability of observations highlights the need to measure losses carefully for specific value chains to identify concretely where significant losses occur. Nonetheless, surveys into the extent, location and causes of food loss and waste are complex and costly. As a result, only 39 countries have officially reported [data](#) to FAO.

EFFORTS TO MONITOR FOOD LOSS AND WASTE AT A MORE DISAGGREGATED SCALE ARE BEING RAMPED UP, BUT INFORMATION IS STILL LIMITED

Efforts are ongoing to improve data on losses and waste at a finer scale. These data will be key, as interventions to reduce food loss and waste require an understanding of where in the food supply chain, for which products, and in which regions or countries food loss and waste occurs. Data should also indicate how large losses are and what their underlying causes and drivers are. Starting in 2015, FAO's Global Initiative on Food Loss and Waste (Save Food) has carried out a number of case studies to identify critical loss points in the food supply chain where food losses have the highest magnitude, the greatest impact on food security, and the largest economic dimensions. This work covers different commodities in the countries of Africa, Asia and Latin America. Its results indicate that harvesting is the most frequently identified critical loss point for all types of food, while inadequate storage facilities and poor handling practices were identified as the main causes of on-farm storage losses. For fruits, roots and tubers, packaging and transportation also appeared critical. These results on critical loss points and underlying causes are valuable in providing guidance when identifying potential interventions for food loss reduction.

EVEN WITH LIMITED INFORMATION, GETTING THE INCENTIVES RIGHT AND OVERCOMING CONSTRAINTS WILL FACILITATE ACTIONS TO REDUCE FOOD LOSS AND WASTE

This report aims to provide guidance on policy and interventions to reduce food loss and waste even in the face of the limited information available. This is based on an incremental argument starting from the **business case** for reducing food loss and waste, where incentives and adequate information can encourage the

private sector to reduce food loss and waste in their own interest. This may also bring benefits to society, and providing information in these situations is particularly important. The incremental approach then continues by making the **economic case** for food loss and waste reduction, looking beyond the business case, and is based on the broader benefits that can accrue to society from reducing food loss and waste. These may result in improved incomes for other actors in society. Other benefits, which will not be financial in nature but are no less important, constitute the final step in the incremental justification for reducing food loss and waste. Among these other benefits, the report focuses on: (i) improved food security and nutrition; and (ii) environmental sustainability. Thinking through each justification for reducing food loss and waste can provide some indication of how and where to intervene.

The business case for reducing food loss and waste rests on the private gains that can be realized by stakeholders who reduce levels of food loss and waste. The assumption is that actors in the food supply chain make rational decisions that maximize their profits (in the case of producers or suppliers) or their well-being (in the case of consumers). Reducing food loss and waste generally entails costs, and suppliers and consumers will only undertake the necessary efforts if these are outweighed by the benefits. In the case of producers, the beneficial impact of reducing food losses by investing in technology or improved practices may be too small in relation to the investment cost. For consumers, the value of their time may be too high to justify efforts to plan food purchases and meal preparation better and to manage food stocks.

The business case revolves around private monetary benefits and costs. Thus, incentivizing the business case will involve identifying options that either increase the net benefits or provide better information on the existing net benefits. Any policies that affect food prices or the costs of

managing waste will also affect the incentives for actors to reduce food loss and waste. For example, if food prices are kept artificially low by subsidies, or waste management costs for individuals are not linked to the amount of waste generated, then the incentive to reduce food loss and waste will diminish.

However, a number of factors may prevent actors from taking fully rational decisions on the levels of food loss and waste acceptable to them. In particular, food operators and consumers may have inadequate information on how much food they lose or waste, on the options available for reducing loss and waste, or on the benefits of doing so. Even the limited data available can be useful in informing people's decisions on food loss and waste. Stakeholders may also face constraints that prevent or deter them from implementing actions to reduce food loss and waste. For example, without financial help private actors in developing countries (especially smallholders) may not be able to bear the high upfront cost associated with implementing such actions. Thus, lack of access to credit can become a barrier to taking measures towards food loss and waste reduction. Improving credit access could be an option for reducing food loss and waste even in the absence of detailed information on where losses occur.

THERE IS A RATIONALE FOR PUBLIC-SECTOR INTERVENTION TO REDUCE FOOD LOSS AND WASTE

The broader case for reducing food loss and waste looks beyond the business case to include gains that society can reap but which individual actors may not take into account. There are three main types of societal gains which justify interventions to reduce food loss and waste beyond the pure business case, namely: (i) increased productivity and economic growth, referred to in this report as the economic case; (ii) improved food security and nutrition; and (iii) mitigation of environmental impacts of losing and wasting

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food, in particular in terms of reducing greenhouse gas (GHG) emissions as well as lowering pressure on land and water resources. The last two societal gains, in particular, are typically seen as externalities of reducing food loss and waste. Each of the three societal gains being pursued has specific characteristics that can provide insights on the most appropriate type of interventions.

The first type of gains can be measured in monetary terms – that is to say, these gains are economic in nature. However, the impact of efforts to reduce food loss and waste depends on how their effect on prices is transmitted throughout the food supply chain; some actors may benefit, others may lose out. Hence, an intervention to reduce food loss and waste should take account of the distributional consequences.

The rationale for government intervention aimed at influencing decisions by individual suppliers and consumers rests on two pillars. First, the incentive for individual actors to reduce food loss or waste – the business case – may be weak and/or these actors may face constraints in implementing them. Therefore, the business case for food loss and waste reduction alone may not lead to a significant reduction in losses and waste. Second, the decisions of individual suppliers and consumers concerning levels of food loss and waste are unlikely to take account of the negative implications for society of food loss and waste. These negative externalities, particularly the environmental impacts, are potentially large and provide a strong justification for public intervention.

Governments can intervene in different ways. If individual suppliers or consumers are unaware of the magnitude and consequences of their losses, governments can raise awareness of the benefits of reducing food loss and waste and convince them of the business case for doing so. Governments can also influence the business case for food loss and waste reduction through

various types of actions or policies. They can improve public services and infrastructure, provide financial incentives through taxes and subsidies or introduce regulations.

When taking action to reduce food loss and waste, the type of externality – food security and nutrition as opposed to environmental impacts – will determine which type of intervention is most appropriate along a value chain and in which geographical location.

THE IMPACT OF REDUCTIONS IN FOOD LOSS AND WASTE ON FOOD SECURITY AND NUTRITION DEPENDS ON WHERE THESE OCCUR ALONG THE SUPPLY CHAIN ...

Food loss and waste has potential effects on food security and nutrition through changes in the four dimensions of food security: food availability, access, utilization and stability. However, the links between food loss and waste reduction and food security are complex, and positive outcomes are not always certain. Reaching acceptable levels of food security and nutrition inevitably implies certain levels of food loss and waste. Maintaining buffers to ensure food stability requires a certain amount of food to be lost or wasted. At the same time, ensuring food safety involves discarding unsafe food, which then gets counted as lost or wasted, while higher-quality diets tend to include more highly perishable foods.

Location and point in the food supply chain matter for the food security and nutrition impact of reducing food loss and waste. How the impacts on the different dimensions of food security play out and affect the food security of different population groups depends on where in the food supply chain the reduction in losses or waste takes place as well as on where nutritionally vulnerable and food-insecure people are located geographically. Importantly, not everybody stands to gain.

Reducing on-farm losses – particularly for small-scale farmers in low-income countries – can allow farmers to improve their diets due to increased food availability and gain higher incomes if selling part of their produce. It can also lead to increased supply and lower prices further along the food supply chain and eventually for consumers. On the other hand, if a processor reduces losses, while this will also lead to increased supply and lower prices further down the food supply chain and eventually for consumers, it may result in farmers seeing reduced demand for their produce and thus lower income and worsening food security. Reducing consumers' food waste may improve their food availability and access, in addition to that of possible direct beneficiaries of food redistribution schemes, but farmers and other supply chain actors may be worse off as they are selling less and/or at lower prices. Also in international food supply chains, reducing food waste by consumers and retailers in high-income countries may negatively affect poor farmers in lower-income countries if they are the primary suppliers.

... AS WELL AS WHERE THEY OCCUR GEOGRAPHICALLY, WHICH IS CRUCIAL IN DESIGNING INTERVENTIONS TO BENEFIT THE FOOD INSECURE

The impact of a reduction in food loss and waste will go beyond the immediate location of the reduction as the effects ripple through the supply chain – leading to lower prices – and more broadly through the economy. However, the exact impact will depend on how closely markets are integrated and how effectively price changes are transmitted. A key factor here is distance or proximity to the location of the reduction. Reducing on-farm losses on small farms in lower-income countries may have a strong local food security impact. On the other hand, reducing food waste among consumers in high-income countries is unlikely to have the positive food security effects generally expected.

The increased availability of food locally in these settings does not mean that these surpluses are available for poor and food-insecure people in a distant country with high levels of food insecurity.

The prevalence of food insecurity can be relevant for determining food loss and waste reduction strategies for a given country's food insecurity challenges. In lower-income countries, where food insecurity is often severe, increasing access to food is critical; and access itself is likely to be closely associated with availability. Preventing food losses at the local level in smallholder production can both alleviate food shortages and increase farmers' incomes, thus improving access. If reductions in losses are large enough to affect prices beyond the local area, the urban food insecure could also benefit. At the other extreme, in high-income countries, the problem of access is relevant for a much smaller share of the population; for many, the priority is nutrition and quality of diet. A broad campaign to reduce food waste is unlikely to benefit the small proportion of people facing food insecurity in high-income countries. For these countries, more targeted interventions, such as food redistribution, can contribute to access to food; however, eliminating remaining levels of food insecurity will also have to rely on a broader set of social policies.

REDUCING FOOD LOSS AND WASTE LESSENS THE ENVIRONMENTAL IMPACT OF FOOD PRODUCTION FOR A GIVEN LEVEL OF FOOD CONSUMPTION

From an environmental perspective, food production is resource-intensive and has significant environmental impacts. If food is lost or wasted, this entails poor use of resources and negative environmental impacts. It is forecast that a growing population and rising incomes will lead to an increase in demand for agricultural products by 35–50 percent between 2012 and 2050, exerting even more pressure on

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the world's natural resources. This emphasizes the urgency of reducing food loss and waste. Independently of the environmental objective, reducing food loss and waste will always improve resource use efficiency because more food reaches the consumer for a given level of resources used (or, conversely, fewer resources may be used to ensure a given level of food reaches the consumer). Such reductions always lower GHG emissions per unit of food consumed. In the context of a growing, wealthier population, using resources more efficiently and reducing GHGs emitted per unit of food consumed will be paramount in meeting growing demand sustainably.

However, improved efficiency does not necessarily reduce the total resources used or GHGs emitted. The overall environmental impact will be the result of price changes associated with the reduction of food loss and waste, which will determine – indirectly – its effect on natural resource use and GHG emissions. For example, if the additional supply arising from fewer losses has the effect of decreasing prices for a product, then consumers may demand more of the product. This will tend to counterbalance the positive environmental effect of the improved efficiency of the food system associated with the reduction in food loss.

CLARITY IN THE ENVIRONMENTAL OBJECTIVES BEING PURSUED WILL BE KEY WHEN DESIGNING AND IMPLEMENTING INTERVENTIONS TO REDUCE FOOD LOSS AND WASTE

Three major types of environmental footprints of food loss and waste are generally quantifiable: GHG emissions (carbon footprint), pressures on land (land footprint) and pressures on water resources (water footprint). These can in turn also affect biodiversity. Using food loss and waste reduction as a means of reaching the environmental objectives enshrined in the SDGs will require an understanding of where

in the food supply chain the loss or waste is incurred; which commodities are involved; which environmental footprints are affected; and what the costs are of intervening to reduce the loss or waste.

The first consideration for an environmentally oriented policymaker is choosing which environmental objective to target and defining the commodities on which to focus. Empirical evidence at the global level on the environmental footprints for major commodity groups suggests that, if the aim is to reduce land use, the primary focus should be on meat and animal products, which account for 60 percent of the land footprint associated with food loss and waste. If the aim is to target water scarcity, cereals and pulses make the largest contribution (more than 70 percent), followed by fruits and vegetables. In terms of GHG emissions associated with food loss and waste, the biggest contribution is again from cereals and pulses (more than 60 percent), followed by roots, tubers and oil-bearing crops. However, the environmental footprint for different commodities also varies across regions and countries, due, *inter alia*, to differences in crop yields and production techniques (e.g. rainfed versus irrigated production or grazing for livestock versus use of animal feed).

THE EFFECTIVENESS OF REDUCING FOOD LOSS AND WASTE IN GENERATING DESIRABLE ENVIRONMENTAL OUTCOMES DEPENDS ON HOW IT AFFECTS PRICES ACROSS COMMODITIES AND LOCATIONS, AND ALONG SUPPLY CHAINS

An intervention to reduce food loss or waste, if sufficiently large, will affect prices upstream and downstream in the supply chain relative to where the intervention occurred. The transmission of prices, combined with the location of the actual environmental damage happening along the food supply chain, will determine the environmental outcome of a

potential intervention to reduce food loss and waste. For instance, the environmental impact may occur mostly in primary production, as is the case for land use and water. Alternatively, it may grow throughout the supply chain, as is the case for GHG emissions. In the first case, an intervention anywhere in the supply chain will lead to an environmental improvement as lower prices are transmitted to producers with an incentive to reduce their production and consequently their use of natural resources. On the other hand, if the objective is to reduce the carbon footprint, interventions at the consumption stage will have the greatest return per unit of avoided food loss and waste.

The transmission of price changes is likely to be stronger between suppliers who have a direct link, as opposed to indirect links through other market agents. If this is the case, an intervention at the specific point or close to the point of the environmental impact is most likely to have a positive environmental effect. This will ensure that lower prices are transmitted effectively to the actors generating the negative impact and induce them to make adjustments in production and use of associated natural resources. If interventions occur downstream, price effects are likely to be diluted and smaller by the time they reach actors generating the environmental impact, so the impact on critical areas will be marginal. For example, reducing consumer waste may lead to a small change in water use in many geographically dispersed locations but not necessarily where it is most needed. For GHG emissions the situation is different since the carbon footprint is global in nature and the geographic location of reduced GHG emissions is irrelevant.

As a rule of thumb, interventions targeted at critical loss points that come immediately after most of the environmental damage associated with a given supply chain have the greatest impact in terms of environmental sustainability.

FOOD LOSS AND WASTE REDUCTIONS HAVE TO BE PLACED IN THE BROADER CONTEXT OF SUSTAINABILITY, EVALUATING SYNERGIES AND TRADE-OFFS

Another important question is whether interventions to reduce food loss and waste are the most effective way to reach environmental and natural resource objectives. Although improvements resulting from food loss and waste reduction are not trivial, empirical studies show that other types of interventions result in larger reductions in some environmental impacts, e.g. improved agricultural production methods and dietary changes. However, the same evidence shows that the strongest impact is obtained by combining different interventions, including food loss and waste reduction. In addition, possible trade-offs with other environmental objectives need to be considered. For example, food loss and waste can be reduced by increasing the use of cold storage and packaging; but expanded cold storage may lead to higher energy use and increased use of packaging could generate more plastic waste. In such cases, enhancing energy efficiency in cold storage chains could play a role in reducing emissions. In terms of packaging, it is important to look at the entire packaging-product system in life cycle analyses to assess properly the total environmental burden of measures adopted.

PUTTING ALL THE PIECES TOGETHER – SOME GUIDING PRINCIPLES FOR POLICYMAKERS

This report is based on an incremental approach that builds on the business case for private investments and efforts to reduce food loss and waste through private incentives. It expands the rationale beyond the business case, to one for public interventions to reduce some of the barriers that prevent producers and consumers from reducing food loss and waste, e.g. generating and/or sharing information on how to reduce food loss and waste. Beyond that,

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public interventions should focus on providing public goods or reducing negative externalities. Two fundamental objectives underlie public policies for reducing food loss and waste: improved food security and nutrition; and environmental sustainability. At the same time, it should be recognized that broader policies to promote overall rural development may allow producers along the supply chain to make investments that will also reduce food losses.

Having worked through the different rationales that can justify both private and public interventions to reduce food loss and waste, it is possible to provide some guiding principles for interventions. Clarity about the objective(s) being pursued is essential for identifying the most appropriate policies and entry points for reducing food loss and waste. If the focus is on economic efficiency, an attractive option is to enable the business case for food loss and waste reduction, wherever it may present itself along the supply chain or geographically. A focus on food security will tend to favour interventions early in the food supply chain, where positive food security impacts will be felt throughout the rest of the supply chain. To reach environmental objectives, food loss and waste reductions need to take place downstream in the supply chain relative to where the environmental impact occurs. Finally, location matters when pursuing food security and nutrition or environmental objectives, the only exception being a fall in GHG emissions, which has the same impact on climate change wherever it occurs.

Different countries will have different objectives to guide their choices. Low-income countries will likely focus on improving food security and nutrition, in addition to the sustainable management of land and water resources. This calls for a focus on reducing food loss and waste early in the supply chain, including at farm level, where impacts will be the strongest and losses tend to be the largest. High-income countries with low levels of food

insecurity will likely place the emphasis on environmental objectives, in particular reducing GHG emissions. This will call for interventions later in the supply chain, in particular retail and consumption, where levels of loss or waste are expected to be the highest.

THE ROAD AHEAD – IMPROVING POLICY COHERENCE, ENHANCING DATA COLLECTION AND MEASURING CAPABILITY, AND MONITORING AND EVALUATING PROGRESS

There may be trade-offs between objectives, and choices may have to be made about which objectives to prioritize. A critical issue is that of policy coherence, which requires that all options are weighed together for their impact so that solutions which promote one objective do not unintentionally harm another. Some policies, for example those for improving food security and nutrition, may actually lead to increased levels of food loss and waste because they involve access to safe and nutritious diets with foods that are often highly perishable. However, this should not be seen as a problem; the basic question is rather whether food loss and waste occurs because of an inefficient and distorted food system, and if it is possible to take measures that reduce food loss and waste without compromising food security and nutrition.

Policy coherence is important also because the amount of food loss and waste that can feasibly be reduced will depend on the costs and benefits relative to the status quo. Public policies affecting food prices can change incentives for consumers and producers to avoid loss and waste of food. If not well designed, agricultural policies or those with food security and nutrition objectives, e.g. food subsidies, may have unintended consequences by creating a disincentive to avoid food loss and waste. Therefore, reducing food loss and waste can also be furthered through the reform of policies that unintentionally lead to greater food loss and waste.

However, first and foremost, it is important to assess whether, and to what extent, an initiative achieves its objective. This requires solid measurement of the magnitude of the problem and effective monitoring and evaluation of interventions. Today the scarcity of solid data on how much food loss and waste occurs, and where, is an obstacle to effective policymaking. The lack of data is particularly acute for food waste at the consumer level because of both methodological challenges and the measurement costs involved. Availability of data on losses varies considerably across countries and commodities, and along the food supply chain. However, efforts towards improved

data collection are under way, not least in the framework of monitoring progress towards SDG Target 12.3 through the Food Loss and Food Waste indices being developed by FAO and UN Environment. A key component of this is the development of standards and concepts, as well as guidelines and capacity building. The expectation is that this will allow countries themselves to improve data collection and effective measurement of food loss and waste. Improving statistical knowledge about food loss and waste is a priority area for FAO, and should be for the international community, as well as all countries interested in monitoring their progress towards reaching the SDGs.

SIERRA LEONE

A farmer checking the rice
seeds stored at Tauropanneh
Agri-business Centre.

©Sebastian Liste/
NOOR for FAO



CHAPTER 1

FOOD LOSS AND WASTE – FRAMING THE ISSUES

Key messages

1 Reducing food loss and waste is an important target of the Sustainable Development Goals (SDGs), as well as a means to achieve other SDG targets, in particular relating to food security, nutrition and environmental sustainability.

2 Globally, around 14 percent of food produced is lost from the post-harvest stage up to, but excluding, the retail stage. Accurate estimates of waste by retailers and consumers are being prepared.

3 It is essential to address the causes of food loss and waste. This will require information on where food loss and waste occurs in the food supply chain and the determinants behind it.

4 Reducing food loss and waste can generate economic benefits, but it will also have a cost. As low-cost options for reductions are exhausted, the cost will increase, thus some level of food loss and waste is inevitable.

5 To reduce food loss and waste and deliver major societal benefits will require a careful analysis of the exact linkages between food loss and waste and food security, nutrition and environmental sustainability.

FOOD LOSS AND WASTE – FRAMING THE ISSUES

FOOD LOSS AND WASTE AND THE SUSTAINABLE DEVELOPMENT GOALS

Losing or wasting food is generally viewed as undesirable and something to be avoided. There are probably few issues in the international policy debate around which there is a stronger consensus.^a

Reducing food loss and waste is seen as a way to lower production costs, improve food security and nutrition, and contribute towards environmental sustainability, notably by easing the pressure on natural resources and decreasing greenhouse gas (GHG) emissions. In the context of the challenge of sustainably feeding a world population projected to reach almost 10 billion in 2050, minimizing food loss and waste and making the most of resources underpinning the food system are considered particularly important.¹

Food loss and waste has become a major global issue and is enshrined in SDG 12 (responsible consumption and production), which even sets a specific target related to the reduction of food loss and waste:

SDG Target 12.3 calls for halving per capita global food waste at retail and consumer levels and reducing food loss along production and supply chains, including post-harvest loss, by 2030.

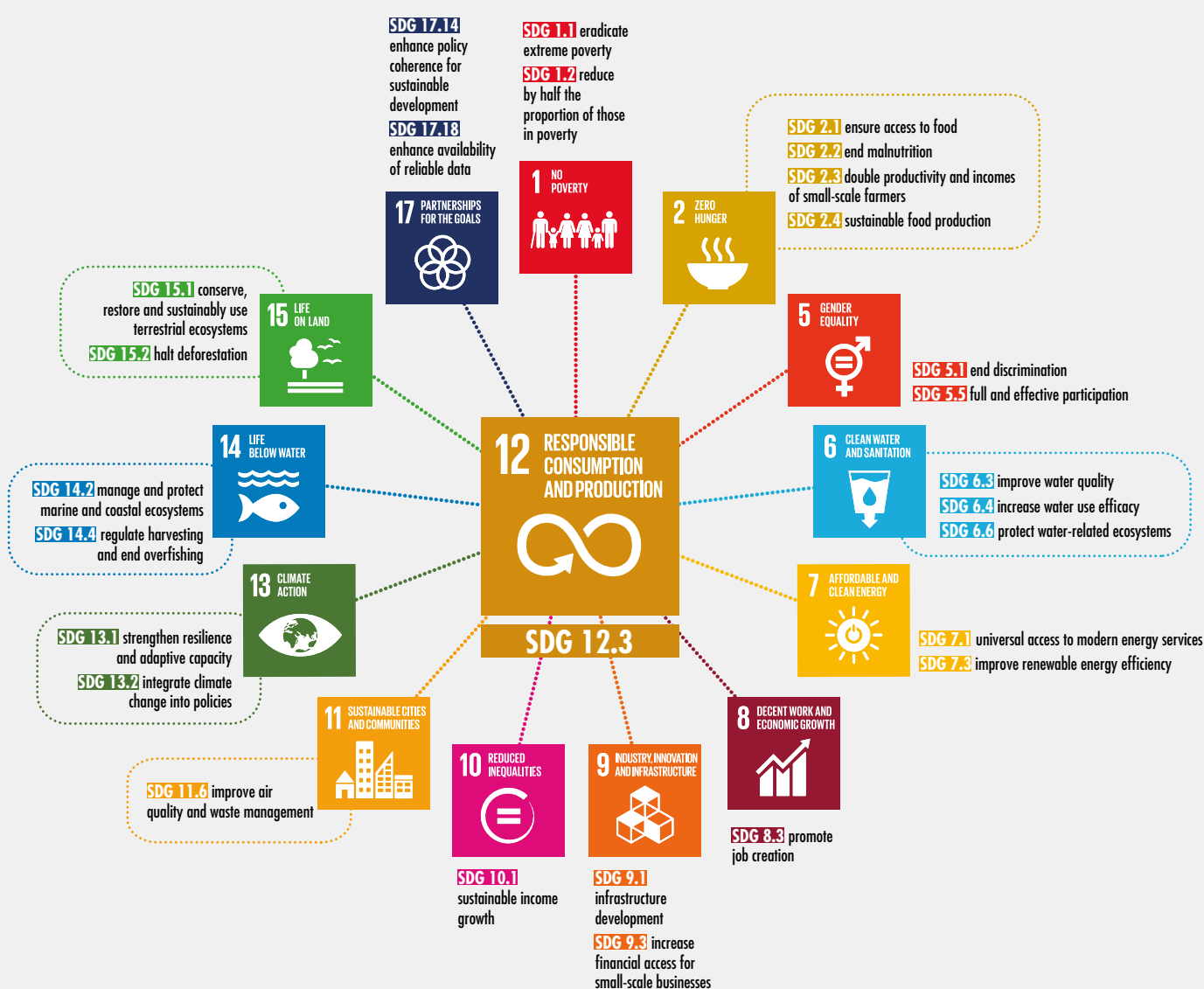
^a There are negative moral and ethical connotations associated with food loss and waste, implicit in particular in the word “waste”, which is perceived as something deliberate or easily avoidable, while in some sense “loss” can be considered a misfortune – something that happens but is not deliberate.

Due to expected impacts on household and business costs, as well as on food security, nutrition, natural resources and the environment, reducing food loss and waste could have wider implications for other SDGs related to the food system, such as SDG 2, which deals with ending hunger and achieving food security and improved nutrition. Possible environmental effects fall under SDG 6 (sustainable water management), SDG 11 (sustainable cities and communities), SDG 13 (climate change), SDG 14 (marine resources) and SDG 15 (terrestrial ecosystems, forests, land and biodiversity). There could also conceivably be knock-on effects on other SDGs: SDG 1 (ending poverty), SDG 8 (sustainable economic growth and decent employment) and SDG 10 (reducing inequalities).

At the same time, progress on other SDGs could have beneficial impacts in terms of reducing food loss and waste. These SDGs include: SDG 5 (gender equality), SDG 7 (affordable and clean energy), SDG 9 (infrastructure, industry and innovation) and SDG 17 (partnerships). However, the importance of these linkages is likely to vary greatly within and between countries and depends on the implementation of food loss and waste reductions. Without considering their likely magnitude and significance, **Figure 1** summarizes the potential linkages between reducing food loss and waste and various SDGs. The rounded boxes refer to the expected impacts on food security, nutrition, natural resources and the environment.

Decreasing food loss and waste seems a simple and reasonable objective. Clearly, it is objectionable to let food deteriorate because of negligence or poor handling or to throw away food that could be consumed by humans.

FIGURE 1
FOOD LOSS AND WASTE AND THE SUSTAINABLE DEVELOPMENT GOALS



NOTE: The rounded boxes refer to the expected impacts on food security, nutrition, natural resources and the environment.

SOURCE: FAO

Therefore, it should be avoided. However, when turning to implementation and deciding on concrete actions, interventions or policies to avoid food loss and waste, the matter becomes

more complicated. Indeed, any policy adopted must take account of the fact that in many cases reducing food loss and waste has a cost and may involve trade-offs with other objectives.

When deciding what action to take to address food loss and waste, a number of questions arise, including:

- ▶ Why is food lost or wasted?
- ▶ How much food is lost or wasted?
- ▶ Why is it important to reduce food loss and waste?
- ▶ How can food loss and waste be reduced?
- ▶ Can *all* food loss and waste be avoided?
- ▶ Who benefits (or loses) from food loss and waste reduction?
- ▶ How can food loss and waste reduction contribute to achieving food security and nutrition or environmental sustainability?

These are some of the questions this report attempts to answer. More broadly, the core questions are: When is food loss and waste a problem? And why should it be reduced? The report argues that food loss and waste reduction should be seen as a way to achieve other objectives – most notably, improvements in the efficiency of the food system, food security and nutrition, and environmental sustainability. ■

WHAT IS FOOD LOSS AND WASTE? A CONCEPTUAL FRAMEWORK

What exactly is food loss and waste? How do we define it? No common definition of food loss and waste exists, although there are several definitions in the literature.^b These definitions often reflect the different problems that stakeholders or analysts focus on or associate with food loss and waste. Indeed, definitions differ across several dimensions, including:

- ▶ What is considered food?
- ▶ Should only the edible parts of food be considered?
- ▶ Is food diverted to other uses (e.g. animal feed) considered lost or wasted?
- ▶ Which stages of the food supply chain are included (e.g. also preharvest loss)?

- ▶ How is food loss distinguished from food waste, if at all?^c

Most definitions focus on the quantitative loss and waste along the food supply chain, but others also consider loss in quality (nutritional, cosmetic, food safety).^d Conceptually it is easier to define and measure the quantitative dimension than qualitative loss and waste, even though there are important measurement issues also for the former. For example, should the measure taken be in terms of volume, caloric or other nutritional content, or economic value? Some definitions even consider overconsumption, beyond actual dietary requirements, as a form of food loss and waste.

For the purposes of this report, **food loss and waste is understood as the decrease in quantity or quality of food along the food supply chain.** The report adopts a generally applicable **conceptual framework** to define food loss and waste (see [Figure 2](#)) that aims to help improve data collection, data comparability and evidence-based regulatory and policy decisions for food loss and waste prevention and reduction. (For a set of definitions of terms used in this report, see [Box 1](#).)

The distinction between food loss and food waste is not only conceptually relevant, but also useful from a policy point of view. Conceptually speaking, **food loss** – the result of decisions and actions by suppliers – affects the supply of food: if food losses are reduced, the supply of food into the food supply chain increases.⁷ Strictly speaking, food loss therefore concerns all stages of the food supply chain up to, but excluding, the point where there is interaction with the final consumer and thus excludes retail, food service providers^e and consumers. **Food waste** is the result of purchasing decisions by consumers, or decisions by retailers and food service providers that affect consumer behaviour. From a policy point of view,

^c For instance, Bellemare *et al.* only use the term food “waste” and do not distinguish between food loss and food waste.³

^d For a measurement of food loss in qualitative terms see, for instance, Delgado *et al.*⁴

^e Food service providers maintain facilities that serve meals and snacks for immediate consumption on site (food away from home). They include restaurants, fast food outlets, caterers, cafeterias, and other places that prepare, serve and sell food to the general public for a profit.⁸

^b For a survey of different definitions and their characteristics see, for example, Chaboud and Daviron.²

BOX 1 DEFINITIONS RELATED TO FOOD LOSS AND WASTE

- ▶ **Food** refers to any substance, whether processed, semi-processed or raw, intended for human consumption. It includes drink, chewing gum and any substance used in the manufacture, preparation or treatment of food but does not include cosmetics, tobacco or substances used only as drugs.⁵ Food products can be of animal or plant origin and are considered food from the moment that: (i) crops are harvest-mature or suitable for their purpose; (ii) animals are ready for slaughter; (iii) milk is drawn from the udder; (iv) eggs are laid by a bird; (v) aquaculture fish is mature in the pond; and (vi) wild fish are caught with fishing gear.
- ▶ **The food supply chain** consists of the following segments: (i) agricultural production and harvest/slaughter/catch; (ii) post-harvest/slaughter/catch operations; (iii) storage; (iv) transportation; (v) processing; (vi) wholesale and retail; and (vii) consumption by households and food services. Agricultural production, harvest and post-harvest/slaughter/catch operations refer to activities where produce is still on the farm or the producer's premises. Post-harvest/slaughter/catch operations include cleaning, grading, sorting and treatments (e.g. for disinfestation on the farm or in a packing facility). Processing includes primary processing operations (e.g. drying, dehusking, deshelling), which often take place on the farm and secondary processing (product transformation). The moment food is consumed or removed from the food supply chain defines the end point of that chain.
- ▶ **A food system** gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food along with the outputs of these activities, including socio-economic and environmental outcomes.⁶
- ▶ **Food loss** is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers.
- ▶ **Food waste** is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers.
- ▶ **Quantitative food loss and waste** (also referred to as physical food loss and waste) is the decrease in the mass of food destined for human consumption as it is removed from the food supply chain. As such, quantitative food loss refers to the decrease in the mass of food destined for human consumption from decisions and actions by food suppliers in the chain. Quantitative food waste is the physical decrease in food mass resulting from decisions and actions by retailers, food services and consumers.
- ▶ **Qualitative food loss and waste** refers to the decrease in food attributes that reduces its value in terms of intended use. It can result in reduced nutritional value (e.g. smaller amounts of vitamin C in bruised fruits) and/or the economic value of food because of non-compliance with quality standards. A reduction in quality may result in unsafe food, presenting risks to consumer health. Qualitative food loss refers to the decrease in food attributes that reduces the value of food in terms of its intended use – it results from decisions and actions by food suppliers in the chain. Qualitative food waste is the same but results from actions by retailers, food services and consumers.

the distinction between food loss and food waste is highly relevant, as the types of interventions that can affect consumer behaviour (food demand) are different from those that encourage suppliers to reduce food losses (food supply).

In practice, the distinction may be more difficult to apply. Indeed, the decisions and actions of retailers and food service providers, despite acting as food suppliers, are often so strongly conditioned by consumer behaviour that the

distinction between loss and waste becomes difficult to disentangle. In this sense, the retail level may constitute a sort of a grey area. For practical and institutional purposes, this report will align with the distinction implicit in the SDG Target 12.3, which refers to “food waste at the retail and consumer levels” and “food losses along production and supply chains”.

The conceptual framework in **Figure 2** distinguishes between the **intended use** of plants and animals produced (both food and non-food economic uses); their **fragmentation** into food, inedible parts, feed and non-feed parts; and, ultimately, their **destination** (as food, productive non-food use, or food loss and waste).

The **intended use** of animal or plant products refers to the original, intended purpose of the product in the chain: to be eaten by humans (food), fed to animals (feed), used as seeds, or for industrial or other purposes (see the “Intended use” rectangles in **Figure 2**). The loss or waste of animal and plant products not originally intended to be eaten by humans is not considered food loss or waste even if this may have implications for food security and nutrition or the environment. Animal and plant products originally intended for food but then **diverted** to a non-food economic use (such as animal feed) are also not considered loss and waste (orange arrows and boxes under “Fragments” and “Destination” in **Figure 2**).

The amount of plants and animals intended for human consumption is then **fragmented** into different uses (food, inedible parts, or other economic/productive uses). To illustrate: while humans consume the interior of a banana, the peel can serve as feed, thereby fragmenting the entire banana into different uses. The inedible parts are food components that, in a particular food supply chain, are not intended for human consumption (e.g. bones, rind).^f The inedible parts, such as the peel of a banana, that are not used for feed or for other economic purposes (shown by the orange arrows) but are

instead disposed of as waste or used in waste management activities are not considered as food loss or waste (shown by the grey arrow).

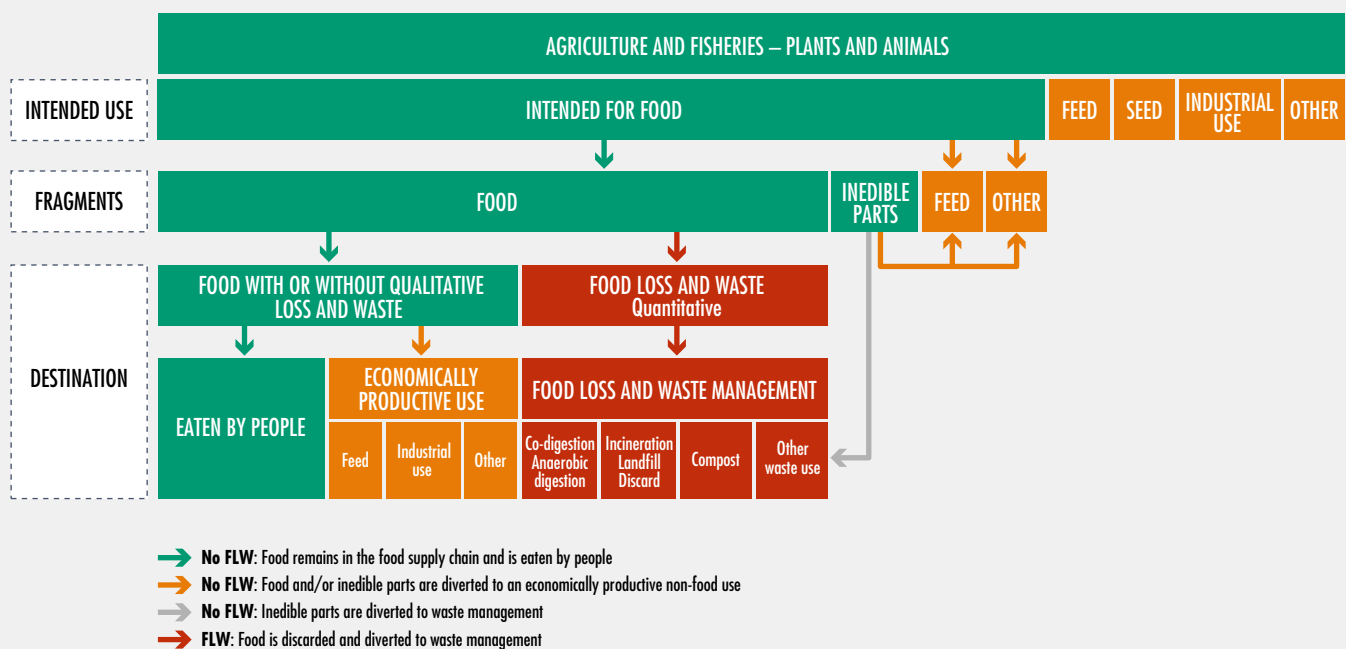
The **destination** refers to the actual use of the amount of edible food destined for human consumption. It may either be eaten by people, even if it has suffered qualitative food loss and waste – e.g. a blemished banana – (shown by the green arrow and box under “Destination”) or diverted to a non-food economic use such as animal feed (the orange boxes). It may suffer quantitative loss or waste if discarded from the food supply chain by either suppliers (food loss) or consumers, retailers and food service providers (food waste) and sent to landfill. Or it may be incinerated, composted or anaerobically digested (represented by the red arrows and boxes).

Note that:

- ▶ Food that has suffered a qualitative loss or waste but is still eaten by humans is not considered a quantitative loss or waste. If either consumers or suppliers discard such food, it is characterized as quantitative food loss or waste, unless diverted to productive use.
- ▶ The reduction in the mass of food resulting from food processing operations such as drying, heating or fermentation is not considered food loss or waste.
- ▶ Food that is fit for consumption and which remains unsold by retailers or food service providers but is then collected and redistributed to other consumers is not considered waste; such redistribution is rather a way to avoid food waste.
- ▶ Food diverted from the food supply chain to a productive non-food use, for example for feed or biofuel use, retains part of its value and is therefore not considered lost or wasted. This is not to say that such diversion has no costs, as it may lower the value of the food.
- ▶ Even though anaerobic digestion generates biogas, it is first and foremost a waste treatment method and no crops are produced exclusively for biogas production. Therefore, food that ends up in this waste management process is considered lost or wasted.

^f What is considered inedible varies among users (e.g. chicken feet are consumed as part of some food supply chains, but not in others). It also changes over time and is influenced by a range of variables, in particular, culture.⁹

FIGURE 2
A CONCEPTUAL FRAMEWORK FOR FOOD LOSS AND WASTE (FLW)



NOTE: "Industrial use" includes biofuels, fibres for packaging material, creating bioplastics (e.g. polylactic acid), making traditional materials such as leather or feathers (e.g. for pillows) and rendering fat, oil or grease into a raw material to make soaps, biodiesel or cosmetics. It does not include anaerobic digestion, as the latter is intended to manage waste. "Other" includes uses such as fertilizer and ground cover. The length of the bars is not representative of the total volume or value of the products concerned.

SOURCE: FAO

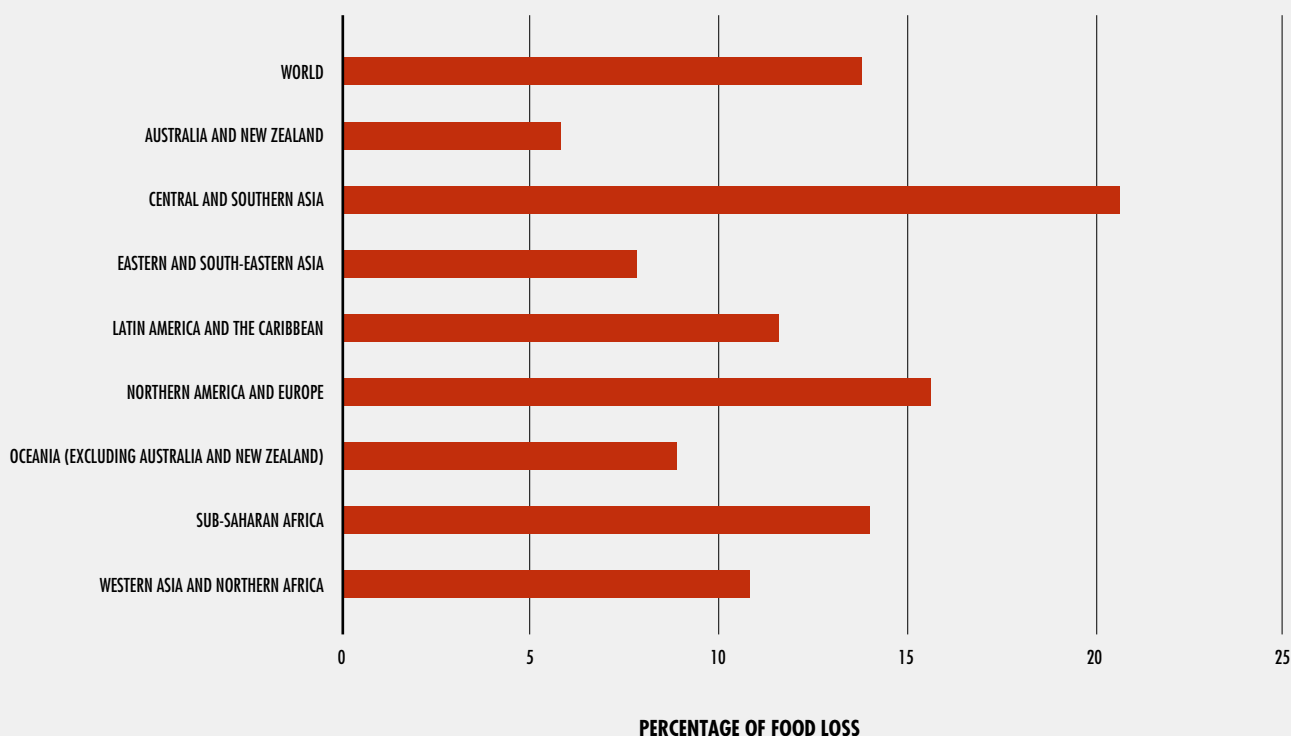
The disposal of lost or wasted food can take various forms, with a more or less detrimental impact on the environment. Composting and anaerobic digestion have a more limited environmental impact than dumping food in a landfill or incineration. The disposal of lost and wasted food is a waste management issue and its study goes beyond the scope of this report. This report clearly focuses on the avoidance, rather than the disposal, of food losses and waste. ■

HOW MUCH FOOD LOSS AND WASTE OCCURS?

What do we actually know about the global magnitude of food loss and waste? Surprisingly little, as it turns out, but the SDG monitoring framework is expected to contribute precisely to bridging this gap through enhanced efforts to collect data that enable estimation of total food loss and waste at the highest possible disaggregated levels.

SDG Target 12.3 calls for halving per capita global food waste at retail and consumer levels by 2030 and reducing food loss (including

FIGURE 3
FOOD LOSS FROM POST-HARVEST TO DISTRIBUTION IN 2016, PERCENTAGES GLOBALLY AND BY REGION



NOTE: Percentage of food loss refers to the physical quantity lost for different commodities divided by the amount produced. An economic weight is used to aggregate percentages at regional or commodity group levels, so that higher-value commodities carry more weight in loss estimation than lower-value ones.

SOURCE: FAO, 2019¹²

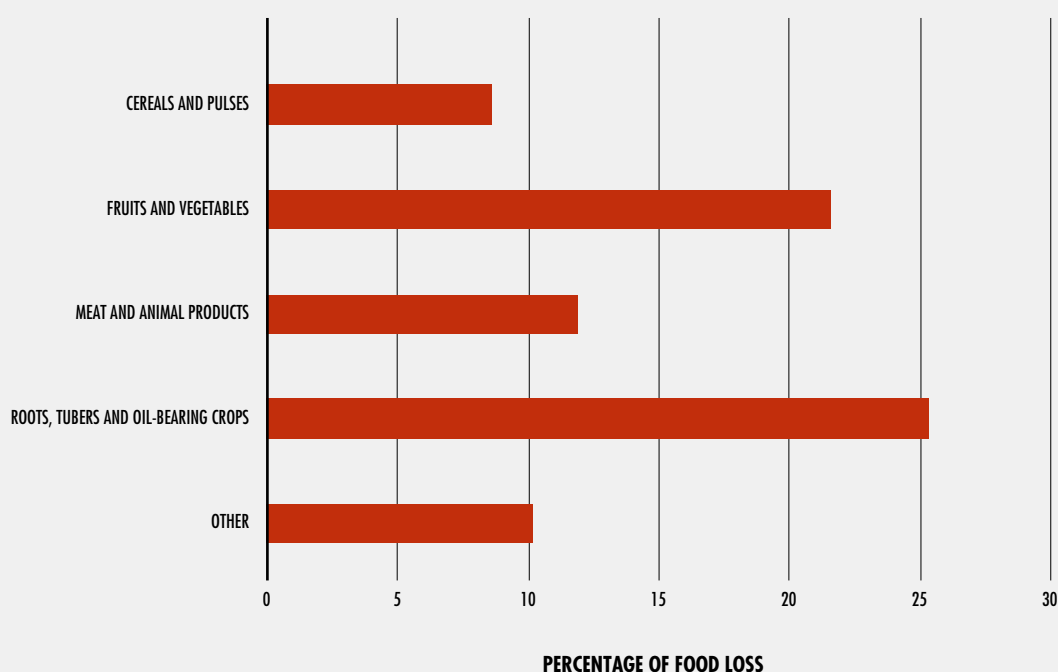
post-harvest loss) along production and supply chains. Progress towards Target 12.3 is measured by Indicator 12.3.1, which has been split into two sub-indicators: the **Food Loss Index** (12.3.1a) and the **Food Waste Index** (12.3.1b).^{10, 11}

Indicators 12.3.1a and 12.3.1b are under the custodianship of two United Nations (UN) agencies, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UN Environment). These two agencies are working together to develop methodologies for the sub-indicators, with FAO leading on the Food Loss Index (FLI) and UN Environment on the Food Waste Index (FWI), given their respective expertise and mandates in these areas. The work of the agencies aims to provide the global community with solid estimates

of both food losses and food waste and improve the underlying data for the estimates and causes of food loss and waste through more accurate surveying across commodity groups, value chains and countries.

Of the two SDG 12.3.1 sub-indicators – FAO's FLI and UN Environment's FWI – the work on developing the FLI and estimating food loss percentages is the most advanced. FAO's FLI has led to the first global estimate released in 2019 that 13.8 percent of food produced in 2016 was lost from the farm up to, but excluding, the retail stage.¹² At the regional level, estimates range from 5–6 percent in Australia and New Zealand to 20–21 percent in Central and Southern Asia (Figure 3). In terms of food groups, roots, tubers and oil-bearing crops report the highest level of loss, followed by fruits and

FIGURE 4
FOOD LOSS FROM POST-HARVEST TO DISTRIBUTION IN 2016, PERCENTAGES BY COMMODITY GROUPS



NOTE: Percentage of food loss refers to the physical quantity lost for different commodities divided by the amount produced. An economic weight is used to aggregate percentages at regional or commodity group levels, so that higher-value commodities carry more weight in loss estimation than lower-value ones.

SOURCE: FAO, 2019¹²

vegetables (Figure 4). It is not surprising that fruits and vegetables incur high levels of loss given their highly perishable nature. Results for roots, tubers and oil-bearing crops are mainly driven by cassava and potato losses, given the significant amount of data reported for these commodities. In fact, cassava is the most perishable of roots and tubers and can deteriorate within two or three days after harvesting; potatoes, on the other hand, require careful handling and proper storage, especially in the warm and humid climates of many developing countries.^{13, 14}

For the FWI, significant work has gone in to developing the methodological framework, but the first estimates of food waste are still in preparation.

Though measuring of food loss is more advanced than that of food waste, challenges

persist. Due to measurability constraints and data unavailability, among other factors, it was necessary for the conceptual framework (Figure 2) and the operational measurement framework to differ in order for FAO to monitor SDG Target 12.3 on food losses (see Box 2). In the operational framework, preharvest and harvest losses are excluded from the global FLI to ensure consistency with the definition of agricultural production used by countries and FAO within the Food Balance Sheet framework. The inclusion of these losses would require redefining production and yield calculations and therefore alter the consistency and comparability of the dataset over time. Another major challenge concerns commodities. Since it is impossible for countries to collect loss data for all commodities, the FLI focuses on ten key commodities from five commodity groups, ranked by production value, within each »

BOX 2 THE FOOD LOSS INDEX METHODOLOGY IN A NUTSHELL

To monitor SDG Target 12.3, FAO has created the **Food Loss Index (FLI)**. The focus of the indicator is on percentages of food removed from the supply chain. The FLI monitors developments in these percentages over time, relative to a base period currently set at 2015, in order to track progress against SDG Target 12.3. Since food losses will vary with total food production, the FLI is based on loss percentages instead of tonnes of lost food. If the index were based on losses in tonnes, then an increase in the FLI could simply be reflecting an increase in production.

For reasons related to measurement, data unavailability and consistency with other statistical definitions and with the SDG Target 12.3 formulation, FAO has adopted the following concepts of food loss and waste in the **operational framework** of the FLI:

- ▶ **Food loss** is all the crop, livestock and fish human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/ slaughter/catch supply chain by being discarded, incinerated or otherwise disposed of, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transportation and processing, as well as imported products, are therefore all included. Loss includes the commodity as a whole with its inedible parts.
- ▶ **Waste** occurs from retail to the final consumption/ demand stages. However, waste is not included in the FLI.

The FLI operational framework differs from the conceptual framework of food loss (shown in Figure 2) with respect to the exclusion of qualitative loss, the inclusion of inedible parts and the limitation of the concept within set boundaries of the food supply chain and selected commodities. As shown in the figure, preharvest and harvest loss³ are excluded from the FLI, but harvest losses can be added for the national FLI. Regarding the qualitative component of food loss, efforts to include it in the FLI are currently underway, for which information on market prices, for instance, may serve as proxies for food quality (see Delgado *et al.* for a similar approach).⁴

As for selecting commodities, given that estimating losses for many commodities across all countries is

operationally challenging, the FLI focuses on the top ten commodities by economic value within five commodity groups for each country:

- (i) cereals and pulses;
- (ii) fruits and vegetables;
- (iii) roots, tubers and oil-bearing crops;
- (iv) animal products; and
- (v) fish and fish products.

Given cost-effectiveness concerns for data collection, the FLI helps improve the evidence base of losses by selecting only a few critical products and focusing on improving the data quality for those.

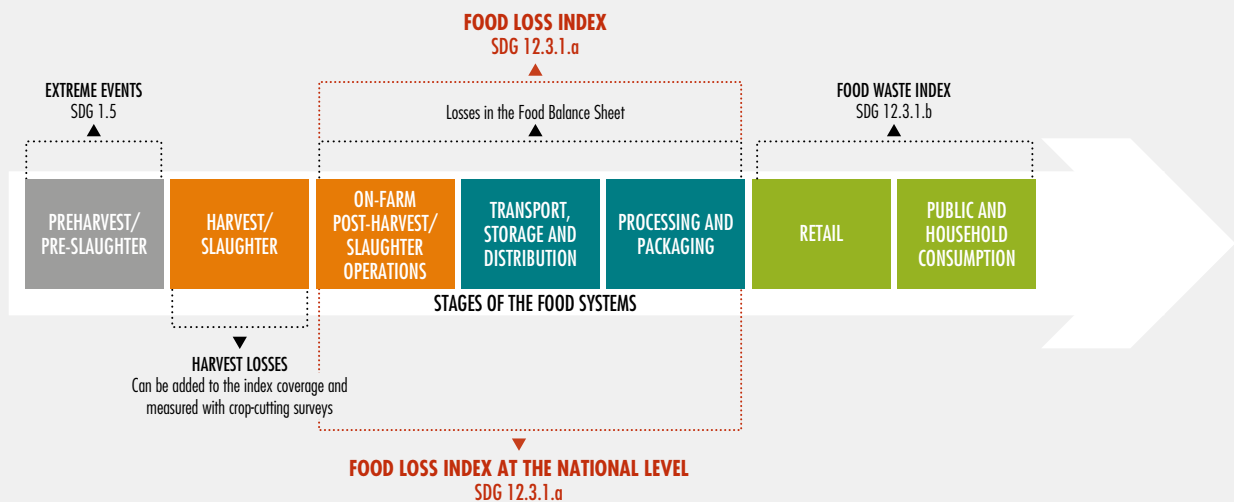
For each country, the FLI estimates loss in physical quantities by commodity and aggregates them into an overall percentage loss at national level using an economic weight equal to the commodities' value of production. The aggregation across commodities is based on farmgate prices expressed in international dollars, i.e. using the same prices for all countries. Consequently, loss of high-value commodities carries a larger weight than low-value commodities. However, the methodology does not take account of the different economic value of loss at various stages in the food supply chain. Indeed, loss further along the supply chain has a higher economic value than loss earlier in the supply chain.

Given that many countries still do not report data on losses, only estimates at the regional and commodity group level are provided in the report. To fill the data gaps and produce loss factors⁵ at the country level, a transparent and reproducible model-based approach has been developed. It uses a set of explanatory variables of causal factors based in the literature and supplements loss percentages with external information gathered from publications and reports (for an overview of the methodology and the estimation model, see the notes in the Technical Annex). As new and better data become available, the approach allows old estimates to be replaced without disrupting the method or the results. However, while the model-based approach used can provide loss estimates on a large scale, it may not perform as well as other modelling approaches in explaining losses at the micro level or at the farm level.

At the global level, the FLI is then a weighted average of the national FLI, using weights equal to the countries' total value of agricultural production in the base period.

BOX 2
(CONTINUED)

SCOPE OF THE FOOD LOSS INDEX ALONG THE FOOD SUPPLY CHAIN



ⁱ Losses occur during harvesting, for example in the case of cereals damaged during cutting or in the process of sorting or grading.

ⁱⁱ Loss factors have been compiled in a database made openly available at www.fao.org/food-loss-and-food-waste/flw-data

SOURCE: FAO, 2018¹⁵

» country.^g The inedible parts of commodities are included, given that separating edible from inedible is operationally demanding and, in some cases, impossible.

Finally, the operational measurement framework adopted by FAO accounts only for quantitative loss. Indeed, the assessment of qualitative food loss and waste would need to monitor the actual value for an attribute as it evolves along the supply chain and compare it to the optimal “reference” level. For example, nutritional content requires the nutritional values at maturity and how they degrade along the supply chain. This is operationally challenging.

The differences between the conceptual framework and the operational measurement

framework reflect the difficulty of collecting rigorous food loss data. If the operational framework were to match the conceptual framework in Figure 2, the FLI would probably produce much higher food loss percentages, indicating a more significant problem than is currently estimated.

FAO’s FLI covers only food loss after harvest and up to, but not including, the retail level, as explained above (see Box 2). The only attempt so far at a comprehensive global food loss and waste estimate throughout the entire food supply chain was prepared in 2011 for FAO by the Swedish Institute for Food and Biotechnology.^{14, 16} However, this study has limitations, clearly recognized in the study itself (see Box 3). It should also be noted that these estimates are not directly comparable with the new FAO estimates because of a number of methodological differences (explained in Box 3). In particular, »

^g For a list of the countries officially reporting data on FLI to FAO between 1990 and 2019, see Table A1 in the Statistical Annex.

BOX 3

FAO'S EARLIER ESTIMATE OF FOOD LOSS AND WASTE – HOW IS IT DIFFERENT FROM THE FLI?

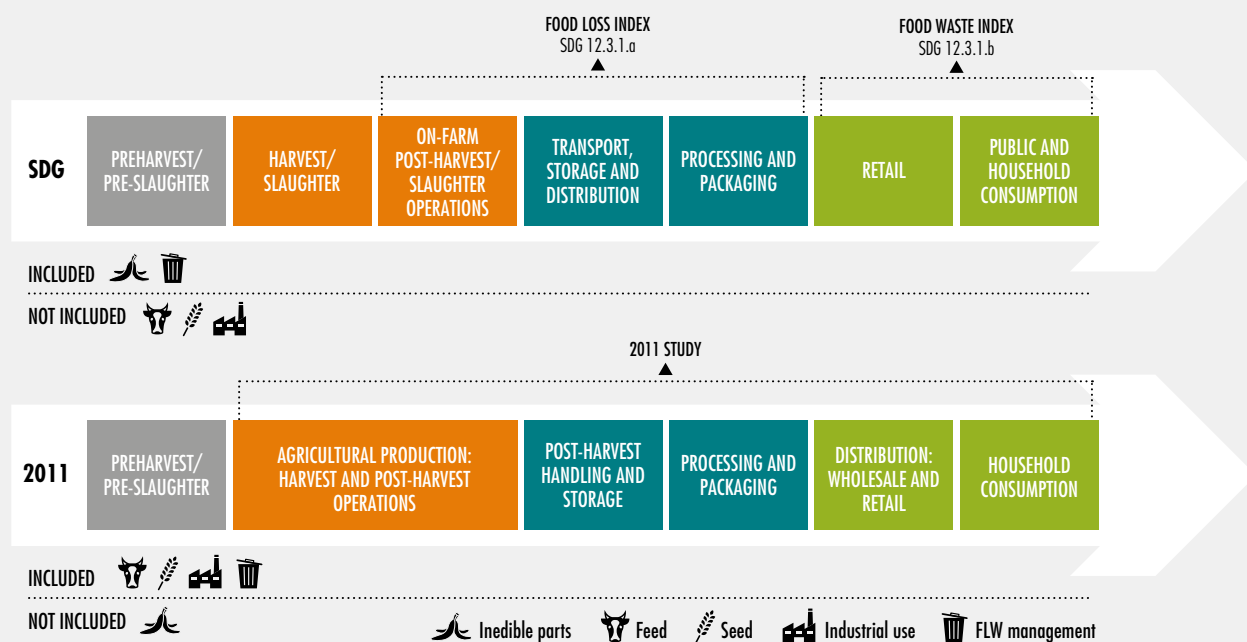
The Swedish Institute for Food and Biotechnology 2011 report for FAO estimated that roughly one-third of edible parts of food produced for human consumption globally was lost or wasted, corresponding to about 1.3 billion tonnes of food per year. The estimate covered all stages from agricultural production up to consumption, while the FLI focuses on losses up to, but excluding, the retail level. To date, this 2011 FAO study is the only one providing global estimates at all levels of the food supply chain and covering all food production sectors.^{14, 16} The estimates are cited widely in public debate.¹⁷ Other subsequent global studies have relied on this report or the same underlying data. For example, Kummu *et al.*,¹⁸ using the same commodity-group specific loss percentages as the FAO study, estimated that, measured in calories, around one-quarter of food (614 kcal/cap/day) was lost in the food supply chain.

The 2011 FAO study was certainly useful in providing a rough indication of the magnitude of food loss and waste and in drawing international attention to the phenomenon. However, the study advises great caution when interpreting the results, given the number

of caveats. The limitations are largely attributable to the intrinsic difficulty in gathering all the information and data for such a comprehensive estimate. Lack of data forced the authors to make a number of assumptions on food loss and waste levels, in particular relating to distribution and consumption. These limitations make the study difficult to replicate.

The study considered all non-food uses (feed, seed and industrial use) as loss or waste. It only considered the edible parts of food while the FLI considers each commodity as a whole, both edible and inedible parts. The study further disaggregated the food supply chain in a different set of stages, relative to the FLI. Also, the study aimed at estimating losses in physical quantities and derived total loss percentages at the end of the process, without taking into account the different economic values of various commodities. Finally, unlike the FLI, the 2011 FAO study did not attempt to incorporate the causal factors of loss in its calculations; in this respect, the study estimates the totality of losses in an almost descriptive way. All these considerations reduce the comparability between the study and the FLI estimates being released through this report (see the figure in this box).

COMPARISON BETWEEN THE FOOD LOSS INDEX AND THE 2011 FAO STUDY



SOURCE: FAO

- » the new estimates do not cover the whole food supply chain. Additionally, relative to the old estimates, the new ones take into account the economic value of the amount lost rather than just quantity (see **Box 4** for different food loss and waste metrics).

FAO prepared the new food loss estimates to monitor progress in the context of the SDGs. Indeed, the inclusion of food loss and waste reduction among the SDG targets has led to enhanced efforts to estimate total food loss and waste. Among the two SDG sub-indicators, the Inter-Agency Expert Group on SDGs has approved the FLI and upgraded it to Tier II, meaning the indicator is conceptually clear and has an internationally established methodology, and that standards are available. The lack of data provided by countries is the main underlying constraint that influences all methodological choices. The estimates are expected to improve over time as data improve. For the FWI, there has been significant work towards the aforementioned methodological framework but a first estimate of retail and household food waste is still to be prepared. ■

WHY IS FOOD LOST OR WASTED?

In theory, actors in the food supply chain make **rational** decisions that allow them to **maximize their profit** (producers) or their **well-being and that of their families** (consumers) – including decisions as to the level of food loss and waste they find acceptable. In this view, a certain level of food loss or waste is unavoidable. Indeed, it may make economic sense for food operators or consumers to tolerate levels of food loss or waste. These levels can be considered as **optimal** from the perspective of producers who maximize their profits or consumers who maximize their well-being.

- For instance, a food processor may suffer some physical loss of food, which could be reduced by investing in more sophisticated machinery or in better operational management, but the cost of doing so exceeds the value of the food that might be recovered; therefore the food processor chooses not to do so.

In general, there are diminishing returns to investments aimed at reducing food loss and waste. This means that it may be relatively inexpensive to obtain early reductions of food loss and waste, but the cost increases for each subsequent reduction. For example, personnel training may be affordable and effective at reducing a share of the losses, but mitigating the remaining losses may require more costly investments in new manufacturing technology.

- It may also be rational from a profit perspective to produce more than required and risk having to discard some food because the cost of a shortfall or not being able to meet demand is higher than the cost of producing too much. In view of climate variability and extremes or low prices at harvest time, farmers may also plant more hectares than they harvest.¹⁹ Likewise, retailers and food service providers will typically have more food on hand or serve more than needed to satisfy clients.
- Some level of food waste by consumers may be the result of rational decisions. If the opportunity cost^h of time for an individual is high, that individual may choose to go food shopping only once a week, purchase more food than necessary and throw away the excess food, rather than purchasing only what is needed more or less on a daily basis.²¹ Likewise, in cases where food represents a limited share of overall household expenditure, consumers may not be very inclined to avoid food waste.

The decision by suppliers and consumers to tolerate more or less food losses or waste – the **direct cause** of food loss and waste – is determined by a number of factors beyond their control, such as pests, climate, and available harvest and post-harvest technologies. These **indirect drivers** include market prices (determined, in turn, by how well markets function), the quality of public services (including, for example, road infrastructure or informational or other social services), the legal framework in place, the culture, etc. They depend on the overall level of economic and

^h Opportunity cost is the cost of something in terms of an opportunity forgone. It is determined by the benefits that might have been obtained by choosing the best alternative opportunity. For example, for farmers the opportunity cost of growing wheat is calculated by estimating what they would have earned if they had grown barley, assuming barley is the best alternative.²⁰

BOX 4 MEASURING FOOD LOSS IN PHYSICAL, CALORIC OR ECONOMIC VALUE – DOES IT MATTER?

New estimates by FAO indicate that 13.8 percent of total food produced in the world is lost between farm and up to, but excluding, retail.¹² These estimates measure loss in physical quantities for different commodities and then apply an economic weight to aggregate them. Commodities that are more valuable carry a larger weight in loss estimation than low-value commodities.

Accounting for the **economic value** of produce is certainly relevant when devising interventions to reduce food loss, taking into account the costs and benefits of reduction. The FAO FLI clearly acknowledges this by attributing a different economic weight to different commodities. Unfortunately, since the indicator aggregates commodities based on respective farmgate prices, it fails to account for the accumulation of value along a food supply chain, attached to successive phases in the delivery of the final product.

However, food loss can be measured in different metrics based on policy objectives being pursued (see the figure in this box). From a nutritional point of view, for instance, it makes sense for food loss percentages to be reported in **caloric units**, using the caloric content of diverse foods. As a result, energy-dense foods will have a greater weight in calculating food loss. In some cases, food loss percentages in calories will be comparatively larger than when measured in tonnes or with an economic weight, if high caloric foods suffer higher loss. For instance, in sub-Saharan Africa cereals such as maize and rice and oil-bearing crops such as

groundnuts are some of the most important commodities in the region's agricultural sector and thus account for a larger share of loss relative to other commodities. Given that they are highly caloric foods, this could explain why loss percentages in sub-Saharan Africa are highest when measured in calories. Conversely, in Central and Southern Asia there is a higher share of meat and animal products (26 percent of quantity by weight in the basket considered for the FLI calculation) being produced compared to sub-Saharan Africa (9 percent of quantity by weight), so that losses in these higher-value supply chains result in proportionately higher losses when measured in economic value terms as opposed to calories.

On the other hand, if a policymaker's focus is on environmental sustainability with the objective of reducing the amount of land or water used in producing watermelons, for example, then looking at purely **physical quantities**, or even hectares of land or cubic metres of water equivalent, can make sense. Although assessing food loss in mass is useful for advocacy and for estimating food security and environmental impacts, it fails to account for the economic or nutritional value of different commodities and can risk attributing a higher weight to low-value products just because they are heavier.

Overall, different food loss metrics have different purposes. Policymakers, businesses and consumers will ultimately decide which metric they wish to use, depending on their objectives.

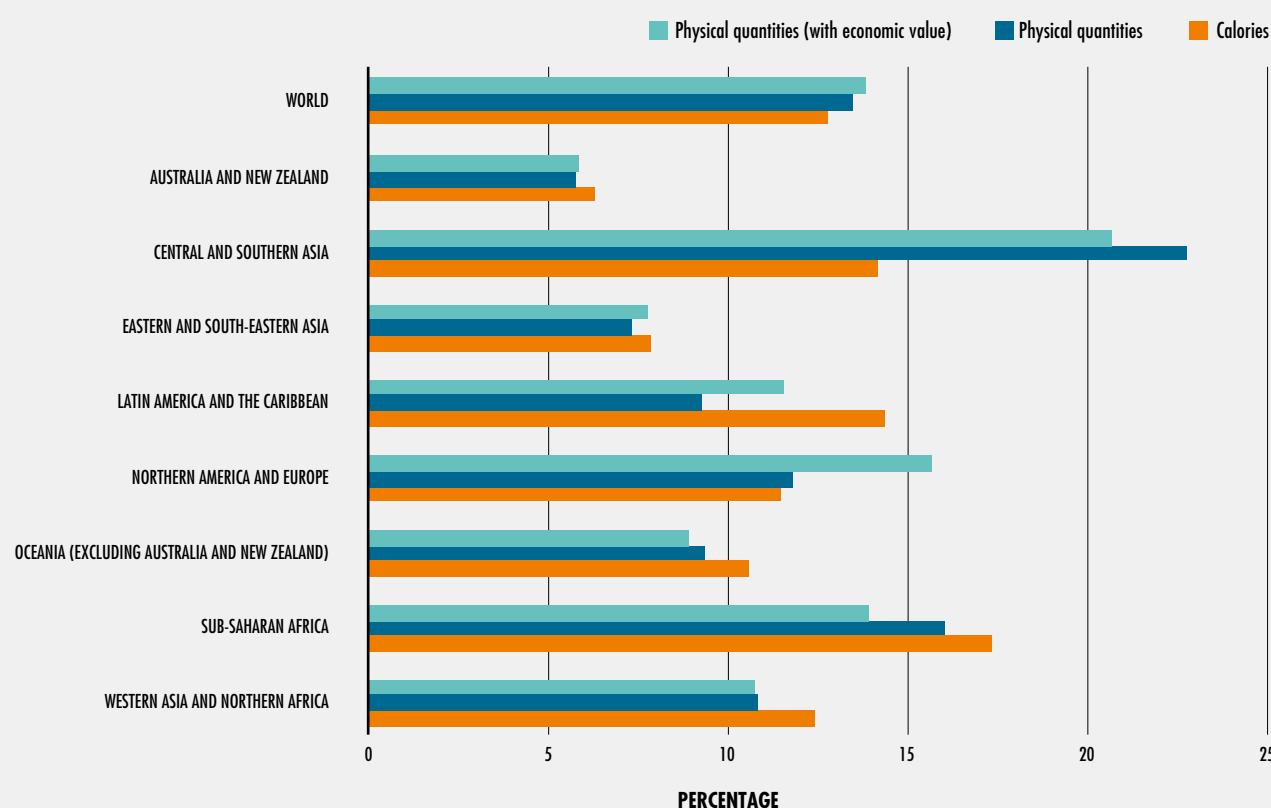
social development under which specific food supply chains and actors operate. Suppliers and consumers may also be influenced by the behaviour of other actors in the food supply chain. For instance, food may be lost at one stage in the food supply chain because it was mishandled at an earlier stage, such as during transportation. Insistence by processors or retailers that their suppliers be able to deliver sufficient amounts of food, even when unforeseen peaks in demand occur, may induce the latter to produce excessive amounts that end up being

discarded. Also, a sudden drop in prices can make it unprofitable to move produce to the next stage of the food supply chain and perishable crops can be left unharvested or dumped on road sides or in landfill.^{22, 23}

Thus, among the factors contributing to food loss and waste, this report distinguishes between **direct causes** – associated with actions (or lack thereof) of individual actors in the food supply chain that directly cause food loss and waste – and **indirect drivers**, which are more systemic

BOX 4
(CONTINUED)

FOOD LOSS PERCENTAGES IN DIFFERENT METRICS, 2016

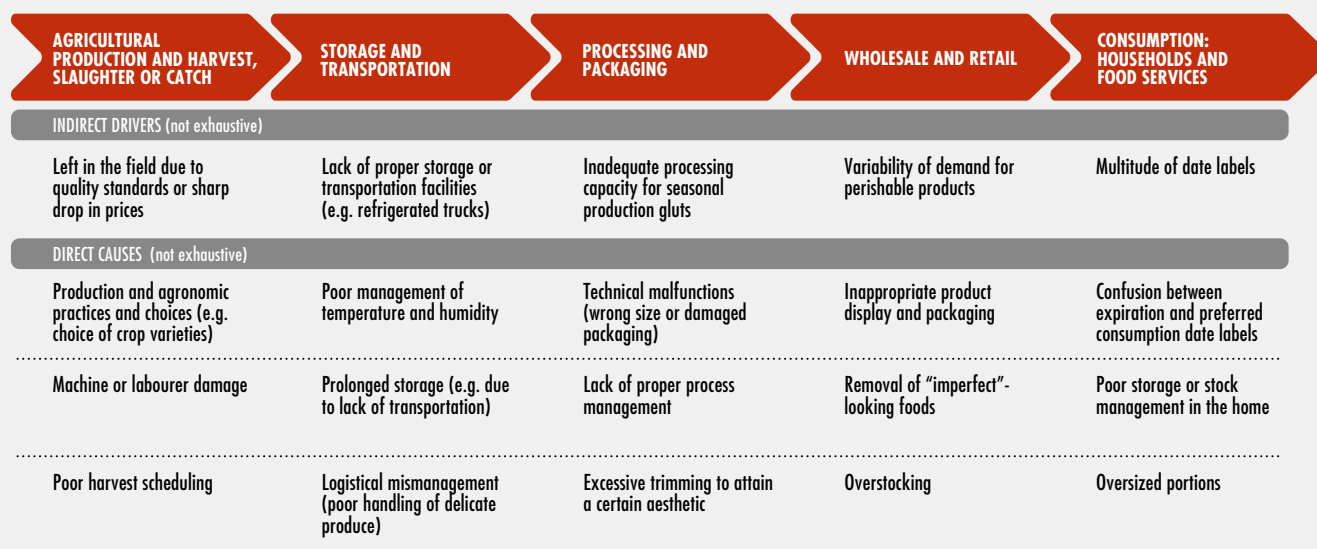
SOURCE: FAO, 2019¹²

and refer to the economic, cultural and political environment of the food system under which actors operate, and thus *influence* food loss and waste. This distinction is particularly relevant for policy. As the indirect drivers condition the decision-making process of individual actors along the supply chain, they may serve as an entry point for policies and interventions aimed at reducing food loss and waste.

The direct causes and indirect drivers of food loss and waste are the results of how well the

food system's elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities relating to the food supply chain interact. Examples of how food loss and waste may occur through a combination of direct causes and indirect drivers can be found across the various stages of the food supply chain (Figure 5). Chapter 2 contains a more evidence-based, in-depth discussion of the behaviour of producers, retailers and consumers and the determinants of food loss and waste.

FIGURE 5
POTENTIAL DIRECT CAUSES AND INDIRECT DRIVERS OF FOOD LOSS AND WASTE



SOURCE: FAO elaboration, based on Lipinski *et al.*, 2013²⁴

If we can assume that food loss and waste is the result of rational behaviour by suppliers and consumers, then why is it a problem? One answer is that there are constraints that inhibit individual suppliers and consumers from behaving optimally from a social perspective. Such constraints reflect market failures and contribute to the occurrence of food loss and waste (see [Box 5](#) for definitions of *market failure*, *externality*, *public good* and *missing market*).²¹ Some examples will help to illustrate this point.

- Where **market failures** result in, for example, poorly functioning credit markets, food supply chain operators may not have access to the financial resources needed to invest in reducing food loss or other productivity-enhancing technology, especially if it involves high upfront costs.²⁵
- Market failures may also be represented by the absence of those types of infrastructure not provided by individuals that are a **public**

good, e.g. roads. This may result in excessive food loss and waste, with negative impacts on the well-being of suppliers and consumers.¹⁹

- Producers and consumers may not have enough reliable **information** about choice options and the impacts of their rational decisions ("bounded rationality"); this may result in food losses or waste that are greater than if caused by perfectly rational decisions.¹⁹

Another reason that an individual's rational behaviour about food loss and waste can be a problem is that producers and consumers seek to maximize their individual well-being and in doing so may ignore the **negative externalities** of their food loss and waste decisions on society at large. For example, individual food supply chain actors may not consider the impact of their decisions on the environment in terms of GHG emissions, unless there is regulation restricting emissions or an associated carbon market that values emission reductions.

BOX 5

DEFINITIONS OF MARKET FAILURE, EXTERNALITY, PUBLIC GOOD AND MISSING MARKET

Market failure is the economic situation where markets do not allocate resources efficiently.²⁶ This means there are opportunities to make some people better off without making other people worse off.

Externality refers to the direct effect on one agent caused by the actions of another, whether positive or negative.²⁷ Pollution emitted by a power plant resulting in acid rain and lakes depleted of fish is an example of a negative externality.²⁸

Public good refers to a product that one individual can enjoy without reducing the amount available to others.

Economists refer to public goods as non-rivalrous and non-excludable. National defence, public parks, clean air and other basic societal goods can all be considered public goods.²⁷

Missing market refers to the economic situation in which there is no market for a certain product because private actors see no prospect of profit, even though the exchange of such an item would be beneficial for society as a whole.^{29,30} For example, farmers will not invest in a technology to reduce loss if the benefits do not accrue to them but instead to actors further down the chain.

Market failures may cause producers and consumers to make decisions leading to levels of food loss or waste that are optimal from their perspective, but not from that of society. They may also prevent economic actors from adopting technologies and practices to reduce food loss and waste which are also to their own benefit. It is essentially these market failures that provide the justification for public interventions and policies aimed at reducing food loss and waste. However, the degree to which some food supply chain actors hold market power (e.g. monopoly) also contributes to market failures and may affect how public decisions are communicated to and enforced upon stakeholders in the food system. In Sri Lanka, for example, the mandatory use of plastic crates enforced by the government was violently opposed by major vegetable suppliers.³¹

The notion of optimal levels of food loss and waste – from a private and a societal perspective – is important for recognizing that some level is both unavoidable and tolerable. However, determining exactly what those optimal levels are is next to impossible because of the empirical challenges involved. The rest of this report, in general, uses the less precise term **acceptable levels** of food loss and waste. ■

WHY DO WE NEED TO REDUCE FOOD LOSS AND WASTE?

Reducing food loss and waste can be a means to achieve a societal objective, such as the SDGs illustrated in [Figure 1](#). This report analyses if and how food loss and waste reductions positively impact on economic outcomes, food security and nutrition, and environmental sustainability. It distinguishes between the **business case** and the **economic case** for reducing food loss and waste. The business case focuses on the benefits accruing to private actors – producers or consumers – in the food supply chain, while the economic case looks at the broader benefits to society.

In some circumstances, when individuals receive additional information or experience changing economic conditions, they may find it to their benefit to reduce food loss and waste. This implies there is a **business case** where the private sector has the right set of incentives to mobilize and achieve reductions in food loss and waste. This may also provide broader economic, social and environmental benefits to society, even though the essential motivation behind reduced food loss and waste is personal.

The **economic case** for reducing food loss and waste looks beyond the benefits accruing to those producers or consumers who reduce food loss and waste. Where it has a negative impact on the well-being of society at large, as highlighted in the previous section, there is an economic case for reducing food loss and waste. Using the resources available more efficiently, be they labour, capital or natural resources, can generate improvements in well-being. As illustrated by **Figure 1**, reducing food loss and waste potentially has indirect effects on poverty, sustainable income growth, food security and nutrition, natural resources and ecosystems. In general, an economic case can be made for reducing food loss and waste – if there are both winners and losers – when the benefits to the winners outweigh the costs to the losers. The benefits from reducing food loss and waste can take different forms. They may lead to increased incomes for other actors – apart from those who actually reduce food loss and waste – and to benefits for society as a whole. Often these benefits can be monetized, and in principle measured, even though in practice this may not be straightforward. Other potential benefits to society cannot be monetized but are no less important. With regard to the latter, this report focuses on: i) **improved food security and nutrition**; and ii) **environmental sustainability**.

In terms of **food security and nutrition**, it is generally assumed that reducing food loss and waste means more food is available for human consumption and this translates into improvements in food security and nutrition. However, the actual effects can be complex and the impacts of food loss and waste reduction on food security and nutrition will depend on the geographical location of food-insecure or nutritionally vulnerable populations, as well as on where in the food supply chain the reductions take place. For instance, a poor farmer will be better off if less food is lost on the farm, which may increase sales or the supply of food for on-farm consumption. However, if less food is lost or wasted further down the food supply chain, the demand for the farmer's products may fall. In the long run, farmers may experience higher incomes if demand increases as a result of a growing population and rising incomes,

provided climate change and pressure on natural resources do not override this effect. However, in the short term, farmers may be worse off from a reduction in food loss and waste further down the food supply chain. The mechanisms through which food loss and waste reductions improve food security and nutrition therefore require careful analysis.

As for the impact of food loss and waste reduction on **environmental sustainability**, it is generally assumed that if food loss and waste are reduced, then less food needs to be produced, processed and transported to feed the world's population. This means fewer natural resources are used and GHG emissions and pollution would be reduced. In addition, if less food ends up in landfill or incinerators, there would be lower GHG emissions and other environmental impacts from waste management practices. This report argues that there is significant potential for improving environmental sustainability through the reduction of food loss and waste. However, the report also shows that the positive impact of this on the environment is not a given and that possible second-round effects and trade-offs should be taken into consideration. For example, if a reduction in food losses results in lower production costs, then producers will produce more with the same amount of resources, which may help meet growing food demand caused by population growth. However, an expansion in food production will have negative impacts on the environment if it leads to more natural resource use or more GHGs being emitted. Meanwhile, if lower production costs translate into lower prices for consumers, it may result in increased demand and encourage wasteful practices, further offsetting the positive impact of reduced food loss and waste on environmental sustainability.

There are certainly societal gains to be made by reducing food loss and waste. However, the precise effects depend on complex interactions within the food system. There is a need to design interventions aimed at reducing food loss and waste to take such interactions into account. ■

SCOPE AND STRUCTURE OF THE REPORT

This report contributes new evidence on the state of food loss and waste and the potential benefits of reducing it. It explores where in the food supply chain food is lost or wasted, and why. Drawing on this evidence, it considers how targeted interventions along the chain stages may achieve other objectives also – most notably, improvements in food security and nutrition and environmental sustainability. The ultimate objective pursued will determine the choice of the most appropriate and cost-effective interventions towards food loss and waste reduction.

This report asserts that if the goals set out in SDG Target 12.3 are to be met, both private and public interventions towards reduced food loss and waste will play an important role. Action by private agents – producers and consumers – can ameliorate the problem to the extent that reducing food loss and waste is profitable for businesses or saves consumers money. However, public intervention is justified where reducing food loss and waste provides economic benefits to society that exceed the costs, or ensures progress towards societal objectives such as improved food security and nutrition and environmental sustainability.

In the analysis of the links between food loss and waste, on the one hand, and food security and nutrition and environmental sustainability, on the other, the report addresses *inter alia* the following questions:

- ▶ Can reducing food loss and waste in a cost-effective way lead to improved food security and nutrition and increased environmental sustainability?
- ▶ If so, in what circumstances and conditions is this the case?
- ▶ What are the costs of doing this and how do they compare with the benefits?
- ▶ Are there trade-offs between the two objectives or with other significant development or environmental objectives?

- ▶ What are the appropriate interventions, programmes and policies to manage levels of food loss and waste?

Throughout the analysis, the report identifies a number of issues that require further careful investigation.

The remainder of the report is structured as follows

Chapter 2 discusses the drivers behind food loss and waste and presents the variation of food loss and waste along the food supply chain, as well as by region and commodity group. **Chapter 3** presents the business and economic case for reducing food loss and waste. **Chapters 4 and 5** look in more detail at the implications of food loss and waste for food security, nutrition and environmental sustainability. In particular, they emphasize the importance of defining measures to reduce food loss and waste on the basis of the objective being pursued. They also address the effectiveness of food loss and waste reduction in reaching food security, nutrition and environmental objectives, assessing the balance between cost and benefits. **Chapter 6** builds on the analysis of the previous chapters to draw policy implications and suggest areas for policy interventions and improved data collection. ■

BANGLADESH

Women collect and control
the quality and fat of the milk
at the Women's Cooperative
Society for Milk.

©FAO/Mohammad
Rakibul Hasan



CHAPTER 2

MONITORING FOOD LOSS AND WASTE ALONG FOOD SUPPLY CHAINS

Key messages

- 1** Global estimates of food loss and waste are important to monitor progress over time, but additional information is needed to understand the variability of food loss and waste percentages across different contexts and at critical loss points along the food supply chain.
- 2** Information on the location, extent and underlying causes of food loss and waste is fundamental in drawing up strategies aimed at food lost and waste reduction.
- 3** The representation of food loss and waste data is imbalanced: most studies focus on fruits, vegetables, cereals and pulses at the farm level, and are from Central and Southern Asia, sub-Saharan Africa and Eastern and South-eastern Asia.
- 4** Loss and waste percentages are generally higher for fruits and vegetables than for cereals and pulses, especially in situations where cold storage or processing conditions are inadequate.
- 5** The wide variability of food loss and waste across commodity groups and supply chain stages, particularly in sub-Saharan Africa and Eastern and South-eastern Asia, points to the need for improved data collection to inform targeted reduction strategies.

MONITORING FOOD LOSS AND WASTE ALONG FOOD SUPPLY CHAINS

The inclusion of food loss and waste reduction in the SDGs has drawn widespread international attention to this problem and has led to enhanced efforts towards reduction. It has been prioritized as a means towards inclusive and sustainable food systems, especially through improvements in environmental sustainability and food security and nutrition.

FAO's Food Loss Index (FLI), the first important attempt to monitor progress towards SDG Target 12.3 (see Chapter 1), estimates that globally, around 14 percent of all food from post-harvest up to, but excluding, retail is lost.¹ However, this estimate, future updates of which will be important for monitoring purposes, is not designed to provide information regarding where in the food supply chain food losses and waste occur, which products and in which regions or countries they occur, or how large they are and what their underlying causes and drivers are.

This chapter opens with a discussion of the importance of moving beyond a global estimate to assess food loss and waste in a context-specific manner and to formulate insights into its complex and diverse causes and drivers. It then presents the results of a comprehensive FAO meta-analysis of currently available studies on the extent, location and causes of food losses and waste at various stages on the food supply chain, spanning different foods and regions. The meta-analysis provides important indications towards targeted policymaking for food loss and waste reduction that take account of geographical and product-related specificities. It also sheds light on the state of the art of food loss and waste monitoring by identifying data gaps behind the estimates for the various stages in supply chains.

The chapter discusses the need for identifying critical loss points – defined as points along the food supply chain where food losses and waste are most prominent and have the greatest impact on food security – to formulate concrete proposals for loss reduction. The identification of critical loss points requires an analysis of specific food supply chains to identify the stages where losses occur and what their impacts are. FAO has developed and applied a case study methodology for food loss analysis to identify critical loss points in selected food supply chains. The final section of this chapter discusses the current challenges of data collection and acknowledges that they constitute an important barrier to understanding the reality of food loss and waste. ■

MOVING BEYOND THE GLOBAL ESTIMATE TO A MORE COMPREHENSIVE ANALYSIS OF FOOD LOSS AND WASTE IN FOOD SUPPLY CHAINS

A global estimate of food loss and waste – such as that for loss released through this report – can provide a sense of how much food is lost or wasted worldwide and help identify the regions and commodity groups in which the issue is particularly prominent. As said, it helps monitor progress towards SDG Target 12.3. It can also play a central part in raising awareness of and promoting advocacy around the issue of food loss and waste. However, such an estimate cannot provide precise information on the extent of losses and waste across different regions, particularly regarding which commodities

BOX 6

FAO'S META-ANALYSIS OF EXISTING STUDIES INTO FOOD LOSS AND WASTE – METHODOLOGY

FAO's meta-analysis on food loss and waste includes more than 460 publications and reports from various sources (including governments, universities and international governmental and non-governmental organizations), containing almost 20 000 data points.ⁱ

This chapter analyses about 2 300 of the 20 000 data points. The analysis excludes studies that measure food loss and waste across entire food supply chains (a reduction of more than 5 500 observations), rather than individual stages within those supply chains, since such studies prevent the analysis of losses or waste along the food supply chain. It also excludes all 9 107 data points from the African Postharvest Losses Information System (APHLIS) because, due to lack of better data and resources, APHLIS allows a single point estimation to be interpolated across time and different crops and regions.ⁱⁱ

More than 65 percent of the data points included in the meta-analysis refer to Central and Southern Asia, followed by sub-Saharan Africa (17 percent) and

Eastern and South-eastern Asia (9 percent). Cereals and pulses account for 28 percent of all data points and fruits and vegetables for 33 percent.ⁱⁱⁱ Note that India accounts for 85 percent of the observations for Central and Southern Asia, highlighting the need for other countries in the region to step up their efforts to measure losses and waste to formulate context-specific reduction strategies. Ghana, Nigeria and the United Republic of Tanzania are the countries in sub-Saharan Africa for which the meta-analysis includes most data.

The studies included often used different measuring methods, which hinders data comparison and may result in a wide range of estimates. Despite these caveats, however, the meta-analysis provides useful insights into the extent and causes of food loss and waste for various regions, commodity groups and stages of the food supply chain. Such insights are essential for policymakers and actors in the food supply chain to formulate and implement strategies to reduce food loss and waste.

ⁱ The dataset underlying the meta-analysis is available at www.fao.org/food-loss-and-food-waste/flw-data. As new food loss and waste estimates are published, FAO will adjust estimates of global loss and waste percentages.²

ⁱⁱ For example, more than 1 000 data points from APHLIS indicated the same value (2.7 percent) for loss during storage for more than 30 countries between 2003 and 2016.

ⁱⁱⁱ For a breakdown of the sample data by region, country, product group, stage in the supply chain and data collection method, see Tables A2–A6 in the Statistical Annex.

are involved and at which stages along the food supply chain losses or waste occur. Such information is crucial for policymakers and individual actors in the food supply chain to formulate and prioritize effective strategies towards food loss and waste reduction.

To this effect, FAO has conducted a major meta-analysis synthesizing the results of a large number of existing studies that measure food loss and waste in countries all over the world. The meta-analysis has served as input for generating the first estimates of the FLI, given the scarcity of official information reported by countries. In addition, the meta-analysis has

helped to detect how food loss and waste varies across stages in the food supply chain and regions and commodity groups; in other words, how context-dependent food loss and waste actually is.

FAO's meta-analysis constitutes the most comprehensive study of existing data on the extent, location and causes of food losses and waste undertaken to date, spanning food supply chains and regions (see Box 6 for more information on its methodology). By assessing variability across the different stages of the food supply chain, commodity groups and regions, FAO's meta-analysis provides essential guidance to countries working towards reducing food loss and waste. »

BOX 7 HOW TO INTERPRET THE GRAPHS IN FIGURES 6, 7 AND 8

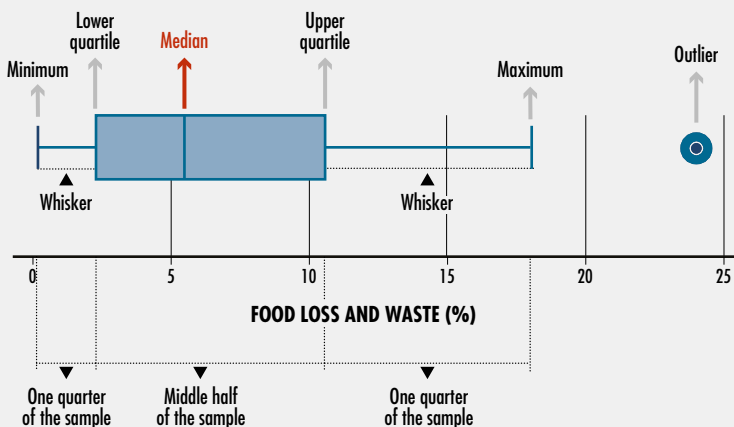
The meta-analysis conducted is meant to generate a comprehensive snapshot of the information available on food loss and waste (see Box 6). Packing all this information in a single concise diagram is challenging. A choice has been made to use box plots as these help to graphically represent the variability of food loss and waste, which is at the core of the analysis (see Figures 6, 7 and 8). Using box plots facilitates understanding of the nature of a whole dataset at a single glance, including the distribution of observed values and the value lying at the midpoint of this distribution, also known as the median.

The figure in this box helps illustrate the usefulness of the box plots in portraying the variability of food loss and waste. More specifically, it shows a close-up of the range of loss percentages in Eastern and South-eastern Asia at the farm level. As it is the case of every box plot, the figure has two parts: a box (blue rectangle) and the whiskers (lines extending horizontally from the box). The start of the box, i.e. the lower quartile moving from the left to the right, represents 25 percent of the dataset. By looking at the figure, it is clear that 25 percent of studies report a loss value lower than 2.25 percent. Similarly, the end of the box, i.e. the upper quartile, represents 75 percent of the data. Again, from the graph, one can conclude that 75 percent of the studies in the region report loss at the

farm level under 10.5 percent. The median (i.e. value lying at the midpoint of the distribution) is a little higher than 5 percent, meaning that half the observations have loss levels equal to or greater than this value, and half have less.

The whiskers indicate variability outside the upper and lower quartiles. The end of the whiskers represents the minimum and maximum values of the distribution, excluding outliers. An outlier is an observation point that is distant from other observations, and thus falls outside of the overall trend that is presented in the data. In box plots, an outlier is a number which is greater than the upper quartile by more than 1.5 times the interquartile range, i.e. the distance between the lower and upper quartile. In this case, it refers to any number above 23 percent. For this reason, the dot on the extreme right side of the figure, a loss value of 24 percent, is an outlier. Since outliers correspond to any value falling beyond the whiskers, they can be numerous and close to the whisker itself. In Central and Southern Asia, for example, in Figure 6A, almost all loss values for cereals and pulses at the level of on-farm post-harvest operations are below 2.4 percent. In this case, following the aforementioned “1.5 times the interquartile range” rule, any percentage above 2.6 will thus be considered an outlier, explaining why there are so many outliers and so close to the whisker itself.

RANGE OF LOSS PERCENTAGES FOR CEREALS AND PULSES DURING ON-FARM POST-HARVEST OPERATIONS IN EASTERN AND SOUTH-EASTERN ASIA



SOURCE: FAO elaboration, based on FAO, 2019²

- » In contrast to the FLI, the meta-analysis includes data on the amount of food wasted by consumers and retailers. However, measuring food waste has proved more complex than food losses. While efforts are underway to define a commonly accepted method to measure food waste, the studies are few and hence the data on food waste included in the meta-analysis are limited. ■

VARIATION IN FOOD LOSS AND WASTE ALONG FOOD SUPPLY CHAINS – RESULTS OF A META-ANALYSIS

While the SDG monitoring requires splitting the food supply chain to cover losses through the FLI on the one hand, and food waste on the other, the meta-analysis is an opportunity to observe the food loss and waste variation along the food supply chain.

From production to wholesale and retail, [Figure 6](#) provides an overview of the main results of FAO's meta-analysis of food loss and waste studies. It shows the range of percentages of food lost or wasted at the various stages of the food supply chain for cereals and pulses ([Figure 6A](#)) and fruits and vegetables ([Figure 6B](#)). The figure contains data for Central and Southern Asia, Eastern and South-eastern Asia and sub-Saharan Africa, while [Figure 7](#) zooms in on the wholesale and retail stage, supplemented by data from Northern America and Europe. Only the consumption stage is excluded from [Figure 6](#), for reasons of data availability, but it is examined independently in [Figure 8](#) with data from Northern America and Europe only. For guidance on how to interpret the graphical analysis in the figures, see [Box 7](#).

The wide ranges of values in [Figure 6](#) highlight the need to measure carefully losses and waste at each stage in the food supply chain to identify where they occur. These points are to be interpreted as snapshots of estimated losses for various stages and commodities at different times. Looking at the ranges in losses – rather than only at the median – is useful for identifying

where loss reduction interventions will have the greatest impact. A comparison of [Figures 6A](#) and [6B](#) shows that the maximum values of losses and waste are higher for fruits and vegetables than for cereals and pulses at all stages in the food supply chain, with the exception of on-farm losses and those during transportation in Eastern and South-eastern Asia.

This is not surprising as fruits and vegetables are more perishable. Nevertheless, the levels of loss and waste of cereals and pulses are still significant, indicating a need for public or private intervention. In addition, the wide range of reported percentages, for example in sub-Saharan Africa and Eastern and South-eastern Asia, highlights the scope for reduction in certain cases. In Central and Southern Asia, by contrast, the range of the loss and waste percentages for cereals and pulses is extremely limited for all stages of the supply chain. This indicates that loss and waste of cereals and pulses seems to be less frequent in the region.

Losses for fruits and vegetables vary greatly, indicating a significant potential for reduction, especially in sub-Saharan Africa and Eastern and South-eastern Asia. The median levels of loss or waste in Central and Southern Asia do not exceed 10 percent at any stage of the supply chain; however, the considerable range in loss and waste percentages indicates an important potential for reduction, particularly during transportation and at the wholesale and retail stage.

The following sub-sections review the meta-analysis in more depth by discussing loss and waste percentages; highlighting where loss estimates indicate the greatest need for interventions; and providing an overview of the key underlying causes of loss and waste for each stage of the food supply chain.

On-farm losses

On-farm food losses can occur before, during or after harvesting; in certain cases, crops may be left unharvested in the field. The causes of on-farm losses are numerous and context-specific. They are often influenced by preharvest factors such as weather conditions, seed quality, crop variety and growing practices, infestation by pests and infections by diseases. »

FIGURE 6
RANGE OF REPORTED FOOD LOSS AND WASTE PERCENTAGES BY SUPPLY CHAIN STAGE, 2000–2017



NOTE: The number of observations is shown in brackets. The dates, 2000–2017, refer to when the measurements were taken; however, the date of publication was used if the study dates were not available or were unclear. For a more detailed explanation of how to interpret the diagrams, see Box 7.

SOURCE: FAO, 2019²

» **Figure 6A** shows that on-farm losses of **cereals and pulses** are highest in sub-Saharan Africa and Eastern and South-eastern Asia. Here, loss ranges from 0.1 to 18 percent; the bulk of these observations concern maize and rice. Meanwhile, more than 90 percent of observations in Central and Southern Asia are from India and report losses of less than 4 percent, indicating that losses of cereals and pulses are not problematic in the country. It should be recognized that almost half of these results are driven by a 2005–2007 nationwide survey to assess post-harvest losses in India.³ It is also interesting to note that over 40 percent of the observations for Central and Southern Asia concern pulses, reflecting their high level of consumption in the region, not least in India, relative to other regions (where less than 2 percent of observations concern pulses).⁴

Figure 6B presents loss percentages for **fruits and vegetables** at farm level for Central and Southern Asia, Eastern and South-eastern Asia and sub-Saharan Africa. Losses are highest in sub-Saharan Africa, where the upper half of the observations report 15 to 50 percent.ⁱ Given this very broad range, an intervention to reduce these losses would be best targeted to the upper end of this range for a greater impact. Losses are lower in Eastern and South-eastern Asia, with the median loss amounting to about 5 percent, and the maximum 12.5 percent (excluding outliers).^j Losses in Central and Southern Asia (the bulk of them in India) are even lower: the median loss amounts to 1.3 percent, and losses range between 0 and about 7 percent (excluding outliers).

The variation in on-farm losses across regions may be partly explained by the range of reasons in the literature. To summarize all possible causes would be impossible, as these are highly context-dependent, based on the crop, commodity group and geography. However, the following categories highlight the key factors at play:

- **Unsuitable harvest timing** – Farmers are often forced to harvest prematurely to meet an urgent need for food or cash, or due to insecurity and fear of theft; in the case of crop rotation, however, they may knowingly harvest too early to plant a more lucrative crop.^{5–7} Harvesting highly perishable food products too early may result in the food lacking flavour or failing to ripen, while harvesting too late may cause it to be fibrous or overripe.⁸ Delayed harvesting can lead to the lignification of crops,^{9, 10} infestation by pests or contamination with aflatoxins (e.g. maize).^{11, 12}
- **Unexpected harsh climatic conditions and environment** – Excessive rainfall or a lack of rain causes significant preharvest and post-harvest losses.^{13–15} Insect and pest infestations are another important cause of losses.^{14, 16, 17}
- **Harvest and handling practices** – Part of a crop may be missed during harvest due to the lack of or inadequate machinery, insufficient or excessive drying of crops, or damage to grains during threshing and shelling.^{13, 18}
- **Infrastructure and marketing challenges** – Farmers may prefer not to market, or even harvest, their crops if, for instance, the cost of reaching markets due to poor transport is too high relative to the market price. Lack of storage facilities is another significant determinant of loss and compounds other causes of loss.¹³

For fish, highly perishable meat and animal products, important causes of loss include improper harvesting, slaughtering, handling or storing practices. Improper fish harvesting techniques lead to the capture of unsaleable (unwanted or inedible) species which are discarded debilitated or dead.^{19–21} In the Amazon River around 15 percent of fish from Colombia and 33 percent of fish from Peru are lost due to attacks from predators, discarding fish which are outside the legal limits, or lack of adequate storage on fishing vessels. Other fish is caught as bycatch using inappropriate nets and then discarded.²² In the case of milk, deficient milking equipment, poor sanitation during milking, inappropriate initial handling (e.g. spillage) and lack of cooling facilities are among the major causes of losses. Poor sanitation can result in the contamination of a whole batch of milk, forcing farmers to discard it entirely.^{21, 23}

ⁱ The results for sub-Saharan Africa should be interpreted with caution in view of the limited sample size (26 observations) and possible inconsistencies in the methodologies used to estimate losses.

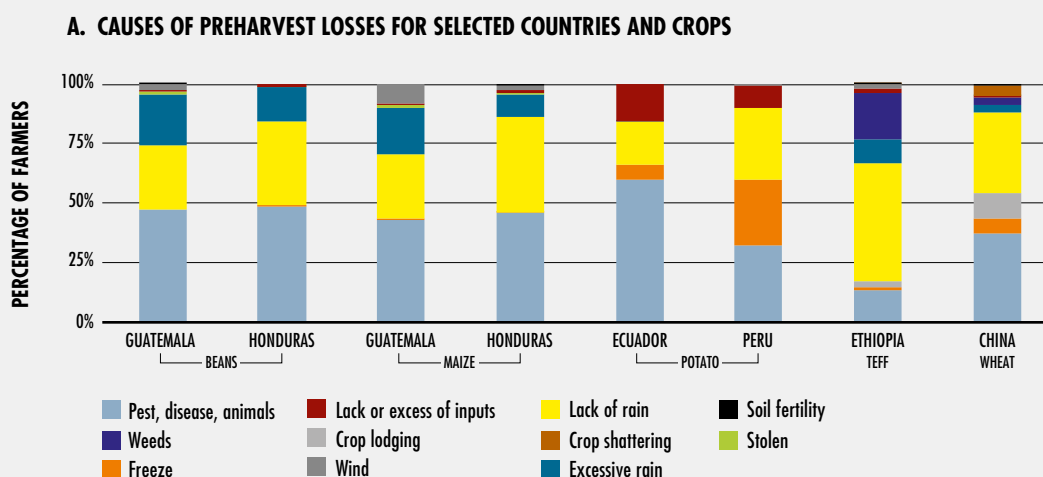
^j As only 20 data points were collected, however, this does not permit a meaningful interpretation of results.

BOX 8 FARMER-REPORTED CAUSES OF ON-FARM LOSSES OF STAPLE CROPS

The International Food Policy Research Institute (IFPRI) recently examined the nature and causes of preharvest, harvest and post-harvest losses for five staple crops in China, Ecuador, Ethiopia, Guatemala, Honduras and Peru. Farmers used specially designed surveys to report on the major causes of losses and the reasons why they left crops in the fields. The main causes of preharvest losses (see Figure A in this box) include infestation by pests and diseases and drought (especially for teff in Ethiopia). The main reason crops are left unharvested (see Figure B) is because of inadequate harvesting techniques; only in Ecuador

are poor quality or small size of produce, shortage of workers or excessive labour costs more important. In China, weather conditions are also one of the main reasons why produce is left in the field.

The main cause of post-harvest losses (see Figure C), with the exception of China and Ethiopia, is damage to crops by workers during harvesting or sorting.¹⁴ In China, mechanical damage is most prevalent, followed by damage caused by labourers during harvesting. In Ethiopia, most post-harvest losses occur because produce is blown away or spilled. Other causes include poor storage and damage by labourers.



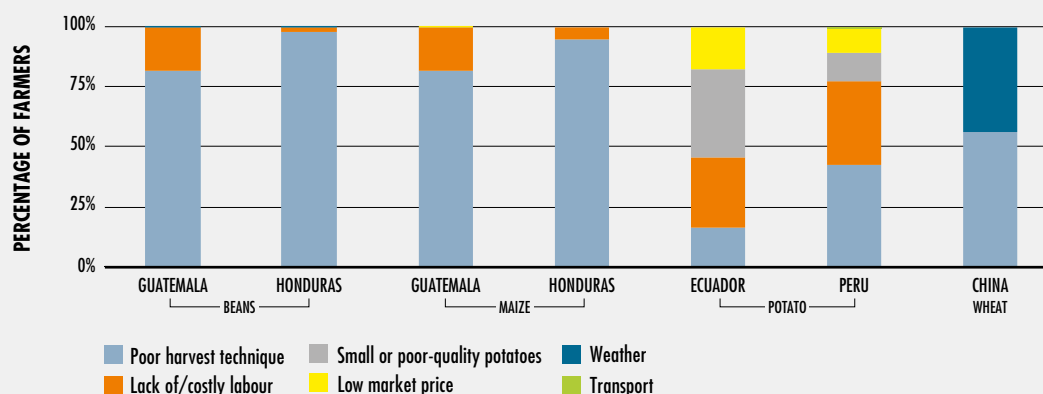
The meta-analysis of on-farm losses makes it possible to gauge the extent and the variability of food loss across regions and commodities around the world. To understand the causes of on-farm losses, in-depth analysis focusing on specific countries is needed. To complement the meta-analysis results for on-farm food losses, **Box 8** provides an overview of the causes of staple crop losses reported by farmers in six different countries, while **Box 9** analyses the indirect drivers of losses in eight countries.

Storage

Storage allows suppliers and consumers to optimize the timing of marketing and consumption decisions and can last from a few hours up to several months. Storage provides stability for producers by helping to prevent losses. For example, depending on the crop, if prices are low, storage can allow producers to delay selling their products and wait for prices to increase; in cases where buyers delay collection, adequate storage can prevent products from spoiling.⁵

BOX 8
(CONTINUED)

B. REASONS WHY PRODUCE IS LEFT UNHARVESTED IN THE FIELD FOR SELECTED COUNTRIES AND CROPS



C. CAUSES OF POST-HARVEST LOSSES FOR SELECTED COUNTRIES AND CROPS

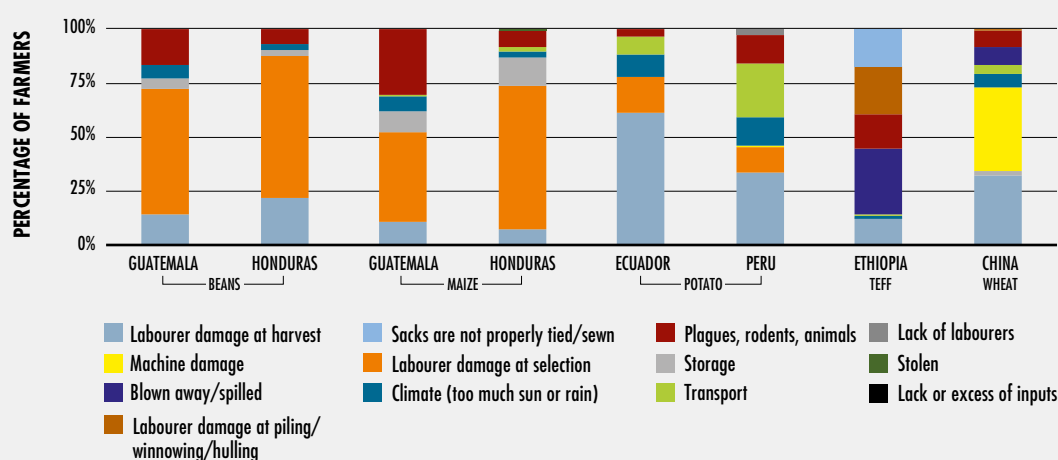
SOURCE: Delgado, Schuster and Torero, 2019¹⁴

Figure 6A shows that the range of losses in cereals and pulses during storage varies significantly from one region to another. Losses appear to be insignificant in Central and Southern Asia, with more than 90 percent of the observations again referring to India and reporting losses of less than 2 percent. In the other two regions, losses during storage are considerable. In sub-Saharan Africa, the median level of loss stands at around 7 percent and the maximum loss reaches 22.5 percent (excluding outliers). Interventions targeting these higher loss

estimates will be most effective, especially when accounting for lessons learned from the literature. Many farmers in sub-Saharan Africa still use traditional grain stores made of grass, wood and mud, which offer little protection against pests.^{5, 25} In some cases, farmers store grains inside their own house due to a lack of storage facilities, or because they are afraid of theft.²⁶ In Eastern and South-eastern Asia, losses range from 0.3 to 15 percent. The variation here is smaller than for sub-Saharan Africa, which means that losses are close to the median of

BOX 9 INDIRECT DRIVERS OF ON-FARM LOSSES OF STAPLE CROPS

A study by IFPRI on the indirect drivers of on-farm post-harvest losses in eight low- and middle-income countries uses data from the World Bank (Living Standard Measurement Study, Integrated Surveys on Agriculture) for Malawi, Nigeria and the United Republic of Tanzania; and IFPRI survey data for the remaining five countries – Ecuador, Ethiopia, Guatemala, Honduras and Peru.²⁴ Owing to data limitations on measuring food losses along the food supply chain, the study examines on-farm post-harvest losses only.

The study identifies all cases of post-harvest losses at the extensive margin, that is the share of farm households that experienced any post-harvest loss; and at the intensive margin, referring to the average percentage of production lost among those farmers reporting losses. Different types of crops are examined for different countries.ⁱ

The study demonstrates that loss percentages vary greatly between households, from one crop to the other and across countries. The data for Malawi, Nigeria and the United Republic of Tanzania allow assessment of distribution of losses across households. No farm households report losses exceeding 30 percent and many report less than 10 percent for several crops.

The study further identifies the determinants of on-farm post-harvest losses at the household level, using econometric models. It considers the demographic characteristics of a household (age, years of education and sex of the household head, and household size), factors relating to production (output level, agricultural assets, equipment owned and inputs used),ⁱⁱ socio-economic factors (per capita household expenditure, access to electricity and/or piped water and

possessing a bank account) and geographic and climatic factors (distance to the nearest road or market, temperatures, precipitation and agroclimatic zone).

The study finds the determinants of post-harvest losses vary greatly from one country to another and between crops (see the table in this box). The likelihood of post-harvest losses increases with the age of the household head in Ethiopia (teff) and the United Republic of Tanzania (maize), but decreases for maize in Guatemala and beans in Honduras, while age was not significant in other cases.ⁱⁱⁱ Other factors, including education, gender, household wealth, ownership of farm assets or use of modern inputs, had an insignificant or ambiguous impact on post-harvest losses across different contexts. One important implication of the heterogeneity of these results is the need to tailor policies aimed at reducing losses to the context of each supply chain.

However, for certain determinants, a consistent pattern emerges from the analysis. First, lack of access to markets, as measured by the distance to the nearest road, is found to contribute significantly to losses in Ecuador (potatoes), Guatemala (maize), Malawi (maize) and Nigeria (maize). It is easier for farmers who are better connected to markets to sell their produce before it spoils. Second, post-harvest losses are found to decrease as output goes up (except for beans in Honduras and maize in Malawi). Where applicable, these common traits are of immediate relevance for policymaking. Improving infrastructure to facilitate transportation of produce to markets is likely to reduce post-harvest losses across contexts, as are efforts to encourage farmers to collaborate, for example by sharing storage facilities.

7 percent – a significant level, similar to the median in sub-Saharan Africa (6.9 percent).

Losses during storage of  **fruits and vegetables** (Figure 6B) vary considerably from one region to another, partly due to the differences in the types of fruits and vegetables that are produced in the regions. Nearly all of the observations for Central and Southern Asia (again, the bulk of them in India) indicate losses of 0–5 percent;

apples, tomatoes and cauliflower are the most represented foods.³ Half of the observations for Eastern and South-eastern Asia refer to cabbage in China and report losses up to 47.5 percent, thereby highlighting the need for loss interventions. Similarly, the 14 observations for sub-Saharan Africa indicate losses of 0.5–35 percent, and mostly refer to mangoes and tomatoes. The high level of food losses in both regions is not surprising given the highly

BOX 9
(CONTINUED)

DETERMINANTS OF ON-FARM POST-HARVEST LOSSES AT THE HOUSEHOLD LEVEL IN SELECTED COUNTRIES

		Age/ experience of household head	Education of household head	Distance to market	Level of farm production	Agricultural assets	Use of modern inputs*
Ethiopia	(teff)	+++	-		--	--	
Malawi	(maize)			++	+		--
Nigeria	(maize)		--	+++	+/-	+/-	++
United Republic of Tanzania	(maize)	+++			--		++
Ecuador	(potatoes)			+++	--		
Guatemala	(maize)	---		+++	--	+++	---
Guatemala	(beans)				--		+++
Honduras	(maize)				+/-	+	--
Honduras	(beans)	---			+++		
Peru	(potatoes)		+++		--		+++

+ or - = significant (for indicated sign) at extensive margin (probability of any post-harvest losses)

++ or -- = significant (for indicated sign) at intensive margin (degree of post-harvest losses)

+++ or --- = significant (for indicated sign) at both extensive and intensive margin

NOTE: * Refers to use of pesticides, herbicides and/or fertilizers.

ⁱ Local and hybrid maize, pigeon pea and bean leaves in Malawi; cowpea, cassava, sorghum and maize in Nigeria; maize, paddy rice, beans and groundnuts in the United Republic of Tanzania; potatoes in Ecuador and Peru; beans and maize in Guatemala and Honduras; and teff in Ethiopia.

ⁱⁱ Studies on the determinants of food losses often include the scale of production as a possible cause, since farmers who are able to produce more tend to deploy better farming practices, and thus incur lower losses. In this study, this is confirmed for most cases at the intensive margin (i.e. for the degree of post-harvest losses). Exceptions include Malawi, Nigeria and Honduras. To prevent the independent variable from influencing the econometric results, considering the level of production is also used to calculate the share of food loss, the data for level of production were transformed into logarithms. Measuring the level of production differently helped to minimize possible estimation bias. In any case, no major differences were found in the sign or size of other determinants when testing the regression models excluding scale of production.

ⁱⁱⁱ While older farmers generally have more experience, and thus better knowledge as to how to handle their produce, they are also less likely to adopt new, improved farming practices.

SOURCE: Nakasone, Delgado and Vos, 2019²⁴

perishable nature of these fruits and vegetables, which can spoil, often within hours, in the absence of adequate storage facilities.^{27, 28} The use of the most adequate type of storage can effectively prevent losses, as seen in Cameroon, where small and medium forest enterprises storing eru, a wild vegetable, in jute bags instead of plastic ones reduced the chance of rotting and increased shelf life by over a week.²⁹

Inadequate storage conditions (e.g. insufficient disinfection) may cause significant losses, and the earlier quality of a product and previous decisions in the supply chain may lead to a shorter shelf life even under the best storage conditions.^{5, 30, 31} Certain climatic conditions, especially heat and moisture, tend to promote biological deterioration (for example, attacks from bacteria, fungi or insects), especially without proper storage and transportation

BOX 10

REFRIGERATED WAREHOUSE CAPACITIES AND NEEDS AROUND THE WORLD

Countries have different needs for refrigerated warehousing, largely due to variations in population, per capita income and geographic location. To facilitate comparisons across countries, the Global Cold Chain Alliance has created a market development index that compares the total refrigerated warehouse capacity of a country to its urban population (a proxy for potential need). Globally, there is an average 0.2 cubic metres of refrigerated warehousing space per urban resident.³⁷ The figure in this box shows that this capacity varies greatly from one country to the next, depending on consumers' buying power and food production and trading patterns.

Generally, higher-income countries have greater refrigerated warehouse capacity relative to potential need. The emerging market economies of Brazil, China, Mexico and Turkey are among the middle-ranked countries in terms of refrigerated space per urban resident (see figure) with relatively high refrigerated warehouse capacity. Meanwhile, several other middle-ranked countries suffer from a large unmet need for refrigerated warehouse space. These generally have low-income households and limited modern retail infrastructure.³⁷

structures to control temperature and humidity. Therefore, adequate cold storage (including, for example, freezing fish or meat) is crucial to prevent food losses and preserve quality at each step of the food supply chain.³²

In lower-income countries, more fresh fruit and vegetable loss is attributable to poor infrastructure than in industrialized countries.³³ In fact, many lower-income countries lose significant amounts of food during storage, often due to poor storage facilities, including refrigerated warehouses.^{34, 35} Whereas in most high-income countries adequate storage facilities, including refrigerated warehouses, are available and effective throughout the supply chain.^{5, 36} If losses do occur during storage, it is generally because of a technical breakdown, poor management of temperature or humidity, or overstocking.⁵ Box 10 discusses how refrigerated warehouse capacities and needs vary globally.

Transportation

Transportation introduces a time gap between various stages of the food supply chain, from production to consumption. This time gap increases the risk that food products, particularly perishable ones, may be damaged or lost; e.g. due to excessive heat or cold, damage in transit, contamination, etc.⁵

As illustrated in Figure 6A, losses of **cereals and pulses** during transportation are negligible in Central and Southern Asia and sub-Saharan

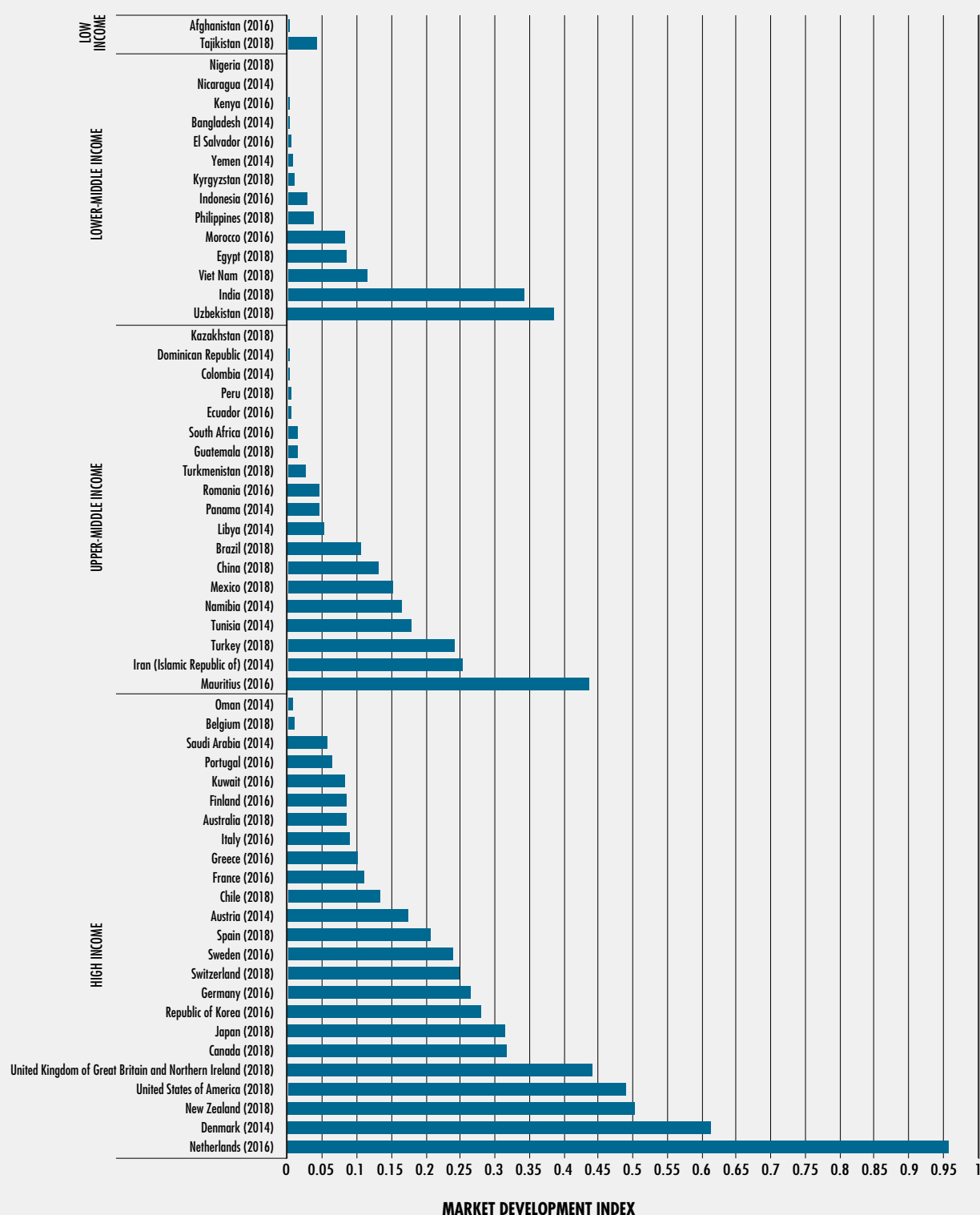
Africa; all 33 data points for these regions present estimates of less than 4 percent, with the exception of one observation. The limited perishability of cereals and pulses may explain the low losses; however, the limited number of observations does not lead to any firm conclusions. Likewise, losses in Eastern and South-eastern Asia are based on a small number of observations (7); therefore the loss estimates (a maximum of 15 percent) may not be very reliable.

Losses of **fruits and vegetables** (Figure 6B) are significantly higher than those for cereals and pulses, hardly surprising given their perishable and fragile nature. Fruits and vegetables are often either poorly packed or not packed at all; transported in open, unrefrigerated trucks; and subject to mechanical injury owing to compression, abrasion and rough handling during handling operations and transportation, making them highly vulnerable to deterioration.^{27, 38} The variability in losses reflects, in part, the significant variation in transport capacity in various supply chains across the world and highlights where interventions may be most effective in preventing such loss.

The upper half of the observations for Central and Southern Asia report losses of 8–25 percent, indicating transportation is a critical loss point for fruits and vegetables. Interventions targeting fruit and vegetable loss during transportation may be particularly effective, especially in Bangladesh and Nepal, where loss levels are »

BOX 10
(CONTINUED)

REFRIGERATED WAREHOUSE CAPACITY IN CUBIC METRES PER URBAN RESIDENT, 2014–2018



NOTE: The market development index, as calculated by the Global Cold Chain Alliance, measures refrigerated warehouse capacity (in cubic metres) per capita in urban areas.

SOURCE: Global Cold Chain Alliance, 2018,³⁷ Table 1

COLOMBIA

A farmer beneficiary of an
FAO productive integration
project shows watermelon
produced through a collective
irrigation network.

©Patrick Zachmann/
Magnum Photos



» highest. In sub-Saharan Africa, the median loss is low (around 2 percent), but percentages vary significantly, with the upper whisker ending at 28 percent (and an outlier estimating loss as high as 35 percent), suggesting there may be room for improvement at this stage of the supply chain. Most studies measured loss for mangoes and tomatoes but the limited number of data points (15) indicates the need to analyse results carefully. The median loss of fruits and vegetables in transit in Eastern and South-eastern Asia stands at around 8 percent – the highest of all the regions. However, the range of variation is smallest. Results indicate that loss is more prominent for lettuce, papayas and tomatoes in the Philippines, but results need to be interpreted with caution given the limited number of estimates (11).

 is a highly perishable food and very susceptible to post-harvest losses resulting from inadequate handling during transportation, storage and processing.¹⁹ In Brazil, 3 percent of all fish caught in the Amazon is lost during transportation, due to bad loading.²² Meanwhile, 7.5 percent of all fish caught in the Amazon in Peru is in an advanced state of decomposition upon landing, and is discarded.²²

During transport, good physical infrastructure and efficient trade logistics are key to preventing food losses. Improved access to roads and railways significantly reduces food losses in 40 countries of various income levels.³⁹ This can be particularly important during the rainy season, when the likelihood of landslides or road blockage increases.⁴⁰ Yet, many lower-income countries lack the infrastructure (vehicles, roads, crates, etc.) and organizational resources to conserve perishables during transportation.²⁷

Box 11 presents an example of an innovative solution for transporting fresh produce in traditional supply chains for mass markets in Southern and South-eastern Asia. Delays caused by inspection of imported products at the point of entry frequently hold up shipments and reduce the shelf life of goods around the world; however, cumbersome paperwork procedures, which, for example, have been documented in Latin America and the Caribbean, exacerbate losses during trade.^{5, 32}

Processing and packaging

The amount of food lost during processing depends in large part on the type of raw material and the nature of the processing operations. Lower-income countries suffer from generally inadequate or non-existent processing facilities, especially for products that are highly perishable (e.g. milk and fish) or seasonal (e.g. mangoes).

Figure 6A presents loss percentages for the processing and packaging of **cereals and pulses**. All 12 observations for Central and Southern Asia are for India, indicating losses of nearly 0 percent. One explanation may be that a third of the crops in the analysis are pulses, which are mostly consumed whole or split, with minimal processing. Chickpeas are usually consumed as flour but only one observation in the meta-analysis concerns them. Meanwhile, all 15 loss estimates for Eastern and South-eastern Asia, and 90 percent of those for sub-Saharan Africa, concern cereals, which often undergo complex processing operations and are therefore more susceptible to losses. It is not surprising that the loss percentage for these two regions is higher than for Central and Southern Asia. The middle 50 percent of observations for Eastern and South-eastern Asia indicate losses ranging from 2.5 to 15 percent, with a median value of 8 percent. In rural areas, processing operations are often manual, resulting in higher losses.³⁰ In the case of rice, milling causes the highest post-harvest losses.⁴⁶ In sub-Saharan Africa, the entire range of observations is higher than for Eastern and South-eastern Asia. While the median loss is low at about 4 percent, the upper whisker reaches 20 percent (excluding outliers), suggesting the need for intervention to prevent loss.

Figure 6B represents losses during processing or packaging for **fruits and vegetables**. The observations for Central and Southern Asia are all below 1 percent, with almost all studies conducted in India. However, the small sample size (15) does not allow the conclusion at this stage that there are no fruit and vegetable losses. In Eastern and South-Eastern Asia, loss percentages range from 0 to 37.5 percent; however, there are only three observations, so no reliable conclusions can be drawn. The analysis

**BOX 11
REDUCING FRUIT AND VEGETABLE LOSSES DURING TRANSPORTATION**

Fruits and vegetables are highly perishable; once harvested, they need to be handled using appropriate practices to maintain their quality. Transport is a critical loss point in the supply chains of fruits and vegetables, owing largely to inadequate use of bulk packaging and poor temperature and relative humidity management. Quality loss resulting from mechanical damage – evidenced by bruising, distortion in the shape of produce, cracking and punctures – leads to discoloration, accelerated ripening, weight loss due to increased transpiration and accelerated decay; these factors, in turn, bring about economic losses.

Through its Technical Cooperation Programme, FAO has introduced improved, sustainable bulk packaging (in the form of stackable and nestable plastic crates), along with good post-harvest management practice, to transport fresh produce in

traditional supply chainsⁱ in a number of Southern and South-eastern Asian countries. The use of crates during transport, as shown in the table in this box, has significantly reduced both quantitative losses (produce rejected outright at the wholesale market) and qualitative losses (produce that is damaged but still saleable). Reduced qualitative losses have allowed wholesalers to diversify their customer base, for example by supplying the hospitality and food services sectors and supermarkets, resulting in economic benefits, not only for them, but also for farmers. Public market retailers and their customers have benefited from better quality produce with a longer shelf life. Where crates replaced single-use plastic bags, this has also brought environmental benefits. Another benefit has been the creation of additional jobs in transporting and cleaning the crates.

POST-HARVEST LOSSES IN BULK-PACKAGED FRUITS AND VEGETABLES TRANSPORTED FROM RURAL TO URBAN CENTRES IN SOUTHERN ASIAN COUNTRIES

Crop	Loss during transportation in sacks (%)	Loss during transportation in plastic crates (%)	Percentage of loss reduction
Tomatoes	16.7	2.2	87
Bananas	5.4	2.1	61
Cauliflower	11.0	4.5	60
Mandarins	7.2	4.1	43
Snap beans	18.0	7.3	60

SOURCE: FAO, 2017, Table 2⁴¹

ⁱ A traditional supply chain is production-driven, where stakeholders lack technical knowledge, technology and competitive and organizational capacities to meet market requirements for safety, quality, consistency and timeliness of supply, as well as the capital to invest in new technologies to upgrade their practices.⁴²

SOURCE: FAO, 2017⁴¹; Rapusas & Rolle, 2009⁴³; FAO, 2011⁴⁴; FAO, 2018⁴⁵

for sub-Saharan Africa comprises seven data points, but the range of values is narrower than for Eastern and South-eastern Asia, varying between 0 and 20.5 percent. More than half the data points concern processing and packaging of mangoes – a highly seasonal, perishable fruit – in Ghana and Kenya. The capacity of the processing

industry in these countries is often insufficient to handle the entire supply of mangoes, resulting in high losses.⁵

The loss of food during processing is usually the result of human error, poor management or technical malfunctions that lead to rejection of

the final product due to non-compliance with standards imposed by buyers. However, low rejection rates are not necessarily an indication that defects are rare; on the contrary, low losses may reflect poor compliance with food safety and quality standards or enforcement thereof.⁵

Processing and packaging play a role in preserving foods. Many tropical crops are preserved by drying and processing into shelf-stable products. Packaging preserves the quality and extends the shelf life of a product, thus reducing food loss or waste. However, it can also harm the environment by creating more plastic waste (see Chapter 5).

Wholesale and retail

The causes of food waste in retail are linked to the limited shelf life of perishable foods, to private quality standards of buyers and variability of demand, in particular for fresh produce.⁴⁷ The actions and decisions by retailers as to the quality and quantity of food products dictate those of their suppliers. Storage conditions, packaging quality and handling practices greatly impact on the quality, shelf life and acceptability of food products.

Figure 7 presents loss and waste levels for cereals and pulses, and fruits and vegetables in Central and Southern Asia, Eastern and South-eastern Asia, Northern America and Europe, and sub-Saharan Africa. Note that the estimates in **Figure 7** may also capture food lost at the wholesale level. Indeed, in many countries, particularly in low-income countries, it is hard to make a distinction between wholesale and retail markets.⁴⁸

Observations on losses for **cereals and pulses** are most prevalent for Central and Southern Asia, showing a range of less than 2 percent loss (excluding outliers). Only three observations are available for Eastern and South-eastern Asia (with losses ranging from 1 to 4.5 percent). The range of losses for Northern America and Europe is the highest among cereals and pulses, yet there are only four observations in the meta-analysis, which does not allow any meaningful conclusions to be drawn.

Fruits and vegetables and other highly perishable foods, such as animal or bakery products and cooked foods, generally suffer higher levels of waste at the retail stage than staples such as cereals, pulses and canned foods.⁵ This is confirmed for the Asian regions and sub-Saharan Africa in **Figure 7**. The deviating result for cereals and pulses in Northern America and Europe can be explained by the limited observations.

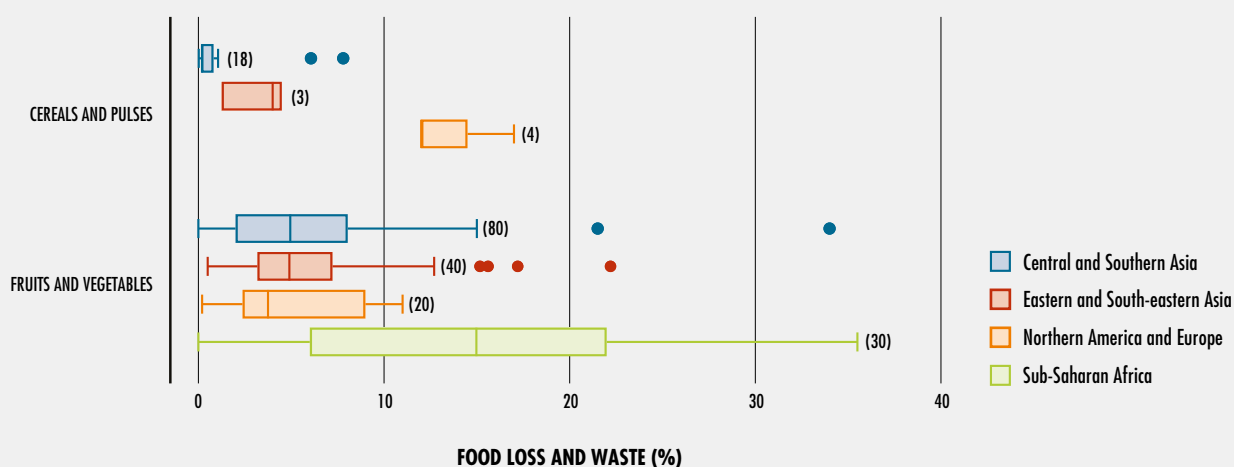
Between 0 and 15 percent of fruits and vegetables are wasted at the retail level in all regions except sub-Saharan Africa, where waste levels are up to 35 percent (excluding outliers), indicating a strong potential for waste reduction in this region. The possible causes of the wide range include inadequate packaging and temperature and humidity control, especially when produce is sold under the hot sun in open-air markets, causing wilting or shrivelling.⁵ Among the Asian regions, the median waste value is the same, but the percentages for Central and Southern Asia have a higher variability, suggesting greater scope for waste reduction.

The median waste percentage for fruits and vegetables at the retail level is lowest in Northern America and Europe. However, it is still significant (3.75 percent) and losses range over 10 percent, supporting the finding that in high-income countries, retail waste levels can be high. It was estimated that 10 percent of all food in the United States of America is wasted in-store.⁴⁹ In Norway, retail accounted for 17 percent of total food waste in 2015.⁵⁰

A factor that contributes to food waste at retail level, especially in high-income countries, is the tendency to sell homogenous and “perfect” produce (in terms of colour, shape, size, etc.). Food that fails to meet these high standards is discarded. While processing less than perfect products into ready-made foods may be a way of using discarded fresh foods, these foods spoil easily and are often discarded at the end of the day or sold at a lower price, reflecting qualitative waste.⁵

Likewise, highly perishable products such as fish are more likely to suffer quality loss or even be discarded if not sold quickly. In Brazil,

FIGURE 7
RANGE OF REPORTED FOOD LOSS AND WASTE PERCENTAGES AT THE WHOLESALE AND RETAIL STAGE, 2001–2017



NOTE: The number of observations is shown in brackets. The dates, 2001–2017, refer to when the measurements were taken; however, the date of publication was used if the study dates were not available or were unclear. For a more detailed explanation of how to interpret the diagram, see Box 7.

SOURCE: FAO, 2019²

for example, unsold fish was found to have a 25 percent price decrease at the end of the first day. Fish that remained unsold after two days saw the price cut by a further 33 percent.²² This situation may be aggravated by inadequate packaging or temperature control.

While some causes of food waste at the retail level apply more to high-income countries, waste can be significant in lower-income countries too. Losses may be higher where there is inadequate protective packaging, temperature and humidity control, such as mixing products like fruits, vegetables, milk and meat in a single cold room or not displaying products properly.⁵

Consumer waste

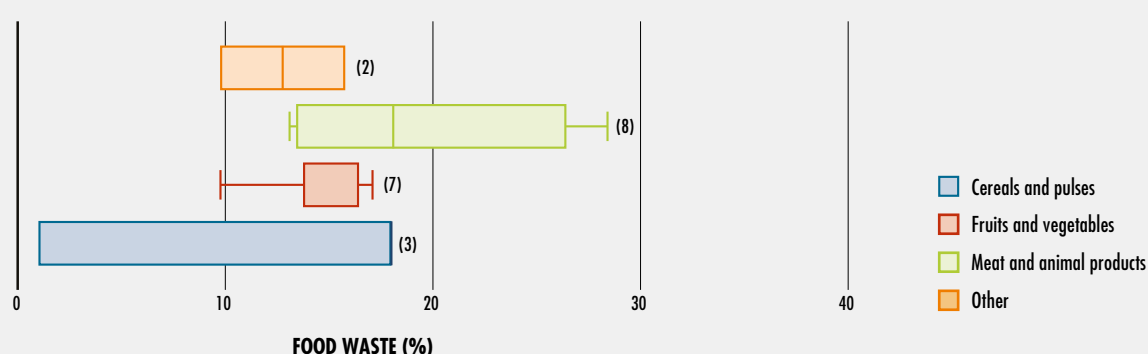
Food waste by consumers is a problem that has been mostly associated with and reported in high-income countries.⁵¹ However, emerging economies are increasingly faced with this

problem. Indeed, the higher the household wealth, the more food consumers waste. Growing incomes and demographic and cultural changes over the past decades have led to changes in eating habits, which often favour convenience.

Figure 8 presents the results of studies on consumer food waste. Of the total of 20 data points, 19 concern the United States of America and one is for Norway. The majority of data points concern animal products, fruits and vegetables, while cereals, pulses and other food products including, *inter alia*, tree nuts and peanuts, are less represented.

The consumption stage is a critical waste point for all types of foods. Waste percentages reach especially high values for highly perishable foods such as animal products (14–37 percent) and fruits and vegetables (9–20 percent). The waste percentages for cereals and pulses and other

FIGURE 8
RANGE OF REPORTED FOOD WASTE PERCENTAGES AT THE CONSUMPTION STAGE IN NORTHERN AMERICA AND EUROPE, 2012–2017



NOTE: The number of observations is shown in brackets. The dates, 2012–2017, refer to when the measurements were taken; however, the date of publication was used if the study dates were not available or were unclear. For a more detailed explanation of how to interpret the diagram, see Box 7.

SOURCE: FAO, 2019²

foods are also significant; however, there are only five observations for these food groups, which limits the validity of the results.

Most consumer food waste studies take place in high-income countries where the problem is particularly acute, especially in the United States of America and Europe. In the United Kingdom of Great Britain and Northern Ireland, the non-governmental organization (NGO) Waste and Resources Action Programme (WRAP) has been particularly active.⁵ It is estimated that the average household in the country wasted GBP (pounds sterling) 470 worth of food in 2015.⁵² Consumer food waste in the United States of America was estimated at USD (United States dollars) 370 per capita in 2010, equal to 9 percent of average per capita food expenditure, or 1 percent of per capita disposable income.⁴⁹

Consumer waste is often a result of poor purchase planning, excess and impulse buying, confusion over labels (“best before” and “use by”), poor in-home storing or stock management, preparing

too much food, and a lack of knowledge on how to use leftovers in other recipes instead of discarding them.^{53–55} An analysis of United Kingdom of Great Britain and Northern Ireland households found that even if people are aware of the problem of food waste, household provisioning routines, time management, accounting for family tastes and food safety concerns can drive day-to-day waste.^{56, 57} The analysis shows that food waste often results from the complex and contradictory demands of everyday life, including time constraints.^{58, 59} Indeed, where time is scarce, consumers buy less often and in greater quantities, resulting in higher levels of waste.⁵

Portion and package size are important determinants of food waste. A study conducted in Sweden suggests that about a quarter of food waste is related to package size.⁶⁰ Consumers may be forced to buy more than they need because only large packages are available. WRAP, for example, has found that around one-third of consumers are unhappy with package sizes and a large majority complain

about the amount of packaging. It was also found that consumers are not necessarily opposed to paying a little more per unit to avoid having to buy too much.⁶¹ A FAO study on self-reported waste in the Philippines found low levels of consumer waste and the conclusions suggest that consumers' ability to purchase small quantities of fruits and vegetables at both public markets and supermarkets reduces waste.⁶²

Promotions or bulk discounts (e.g. three-for-two or economic packages) may entice consumers to buy on impulse, which encourages waste.^{5, 63} In the United Kingdom of Great Britain and Northern Ireland, promotions make up a third of grocery expenditure and the trend is increasing.⁶⁴ Significant quantities of food are also wasted at food service outlets, including school canteens and restaurants.^{34, 65–67}

The socio-economic and demographic characteristics of a household also influence the level of food waste it produces.³³ Small households and high-income households generally waste more food, because the amount of food they buy and prepare is usually larger than the amount they can consume. Large packaging size may be a driver of higher food waste levels, as well as the fact that the higher a household's income is, the lower the relative value of food is for that household.⁵ Culturally, food may also be used as a symbol of prosperity. Households with a higher socio-economic status may purchase more, and more varied, food especially if this is visible to others (for example, at social events); such behaviour leads to more food waste.²⁸ However, these broad tendencies vary considerably between countries and regions.⁵⁴ Food waste studies must take due account of the role of social and cultural drivers in food consumption patterns and attitudes towards food.⁵ ■

THE IDENTIFICATION OF CRITICAL LOSS POINTS

So far, the chapter has focused on the results of the meta-analysis on the extent of food loss and waste for various regions, commodity groups and stages along the food supply chain. Despite providing essential input to the FLI and information useful for targeted reduction measures, such an analysis is not intended to identify critical loss points in specific food supply chains. This requires a comprehensive assessment of losses throughout the whole food supply chain, to identify the stages where losses occur and what their impacts are. This is essential to guide actors in how to significantly reduce food losses in key supply chains and improve food security and farmers' incomes.

Since 2015, FAO's Global Initiative on Food Loss and Waste (Save Food) has carried out a number of case studies in almost 30 countries^k to identify critical loss points for crops, milk and fish produced by smallholders, using a common methodology developed that same year. Due to a common methodology, a comparison of the various studies is possible, although the studies should not be considered as nationally representative.⁶⁹ The objectives of the case studies are to:

- identify and assess the main causes of food loss in specific food supply chains;
- analyse the solutions for reducing food loss with respect to their technical and economic feasibility, food quality and safety requirements, social acceptability and environmental sustainability; and
- formulate concrete proposals for a food loss reduction programme for specific food supply chains.

The FAO case study methodology for food loss analysis is a useful tool for identifying critical loss points in a systematic and comparable manner and allows for trends and common

^k The countries are: Angola, Botswana, Burkina Faso, Cameroon, Colombia, Côte d'Ivoire, Democratic Republic of the Congo, Dominican Republic, Egypt, Eswatini, Ethiopia, Guyana, India, Jamaica, Kenya, Lebanon, Malawi, Morocco, Namibia, Rwanda, Saint Lucia, Timor-Leste, Trinidad and Tobago, Tunisia, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.⁶⁸

BOX 12

FAO'S SAVE FOOD CASE STUDIES ON CRITICAL LOSS POINTS FOR CROPS, MILK AND FISH

FAO's case study methodology for food loss analysis has been applied by FAO's Global Initiative on Food Loss and Waste (Save Food) since 2015 in 88 food supply chains across 28 countries. The common methodology foresees the following steps: (i) screening – initial research into what is known that identifies priority food supply chains; (ii) field investigation – interviews, surveys, studies in the field with stakeholders; (iii) load tracking – loss assessment at critical loss points; and (iv) synthesis – analysis of causes of losses and solutions. The ultimate objective is to outline an intervention programme for reduction in the food losses identified, at the local, subnational or national level.

Out of the 88 critical loss point studies in smallholder production, 56 were reviewed in a synthesis report.⁶⁸ Over 70 percent of these studies were conducted in sub-Saharan Africa, followed by Asia (12.5 percent) and Latin America (16 percent). Cereals accounted for almost half of the studies (nearly all of them in sub-Saharan Africa), followed by fruits (21 percent), legumes (11 percent) and roots and tubers (11 percent).

Harvesting appears to be a critical loss point for all types of food in over 70 percent of the case studies. In Africa in particular, the critical loss points for cereal grains and legumes are consistently at the harvesting and on-farm storage stages, regardless of location or climate. The causes of grain loss at harvesting reported most frequently by farmers include attacks by pests and

insects and the effects of diseases, adverse climatic conditions (e.g. rainfall during harvesting), inappropriate timing of the harvest and lack of labour or funds. Inadequate storage facilities (e.g. insufficient ventilation) and poor handling practices are the main causes of on-farm storage losses.

Likewise, harvesting is identified as the most common critical loss point for roots, tubers and fruits, together with packing (handling and treatment operations) and transportation. For fruits, the most frequently reported causes of loss during harvest relate to the stage of maturity, timing and scheduling, poor sorting, handling and harvesting methods, adverse climatic conditions, diseases and attacks by insects and birds. Losses during packing and transportation were mostly associated with poor handling, inadequate storage conditions and inappropriate packaging.⁶⁸

These findings show the need for great attention to the timing and methods of harvesting, especially since what happens during the harvest may determine both quantitative and qualitative losses further along the chain. To reduce on-farm losses, farmers need training to help determine the point of maturity of their crops, to time the harvest accordingly and to protect crops from adverse weather conditions, diseases and attacks by pests and insects.⁶⁸ Although more studies are needed to confirm the findings of Save Food's case studies, the consistent findings (especially for grains and legumes in sub-Saharan Africa) as to the location, extent and causes of critical loss points confirm their reliability.

solutions to be identified. It is also designed to complement national analyses. So far, it has been effective in directing attention to the food loss situation in a range of countries and commodities by several stakeholders. In some cases, governments, with the support of donors, have moved on to pilot the implementation of the recommended interventions to generate evidence about their impact on losses and economic returns.⁶⁸

Box 12 provides a summary of the main findings to date. They suggest that harvesting is a common critical loss point for all commodities (identified in over 70 percent of case studies). Indeed, for grains and legumes, critical loss points were consistently found during harvesting and on-farm storage, particularly in Africa, regardless of location or climate. Likewise, for fruits, roots and tubers, harvesting appears to be a critical loss point along with packing (handling

and treatment operations) and transportation. Most reported causes relate to the stage of maturity, timing and scheduling; poor handling and harvesting methods; adverse climatic conditions; and attacks by pests, insects and effects of diseases. These results are useful in targeting interventions to reduce losses as they suggest the need to provide farmers with training to identify the point of maturity of their crops, to improve their harvesting and handling methods, and to protect crops from weather shocks, pests, insects and diseases.

The FAO case study analysis of critical loss points contrasts with the meta-analysis presented above. The meta-analysis is based on a large collection of existing studies assessing food loss and waste across the world, which did not necessarily follow the food supply chains to identify the stage of greatest loss, as was done in the FAO case study methodology to identify critical loss points. Nor were stakeholders necessarily engaged to determine the food supply chains on which food loss and waste has the greatest impact – which did happen to be the case in the identification of critical loss points. While the meta-analysis provides a more comprehensive overview into the extent of food loss and waste across different regions, stages of the food supply chain and commodities, the analysis of critical loss points makes it possible to identify losses and their causes in specific food supply chains with stakeholder involvement. However, critical loss points are only available for a selected number of countries and food supply chains and exclusively study losses in smallholder supply chains. ■

CHALLENGES OF DATA COLLECTION

Many countries around the world recognize the importance of reducing food loss and waste and this has been enshrined in the SDGs. Now comes the next step – as argued earlier in this chapter, identifying the causes and drivers of food loss and waste, formulating possible reduction solutions, prioritizing objectives and monitoring progress towards these objectives will require more reliable, comparable and transparent data. As of yet, major data gaps remain, for various reasons.

First, divergent food loss and waste definitions and measuring methods and metrics make comparing studies across countries and food supply chains and over time very difficult, sometimes even impossible.^{5, 13} For example, the terms “food loss” and “food waste” are often used interchangeably. In addition, various methods of data collection may result in the under- or over-reporting of food loss and waste. Self-reported estimates often under-report the real amount of food lost or wasted.^{14, 70} While in many respects expert opinions are useful for defining the problems and identifying hot spots (especially given the complexity of collecting information on determinant factors), they often do not change or update their opinions over time, thereby embedding their biases in the underlying data upon which countries build policies.⁴⁸

Second, surveys on the extent, location and causes of food loss and waste are complex, time-consuming and costly and may require collaboration between various specialists and the carrying of heavy equipment for field operations (e.g. weighing and carrying rice from remote areas to measure loss during drying). Moreover, food supply chains for different food products may differ greatly in terms of their characteristics, processes, stages and agents involved; surveys must take due account of these factors. In addition, data must be collected in a consistent manner, at a relevant geographical scale, and a proper sampling strategy needs to be implemented at the different nodes of the food supply chain. However, the technical and organizational capacities and funds necessary to carry out such complex surveys are often lacking. Thus, even where they exist, data points are few and often show considerable uncertainties.⁷¹

Because of these complexities, it is common for studies to extrapolate loss estimates to other time periods, or even to neighbouring regions and other foods from the same product group. Such studies provide only an approximate view of reality, and fail to produce the reliable and accurate estimates needed for targeted policymaking. An example of such a study is the often cited African Postharvest Losses Information System (APHLIS) for post-harvest losses of cereals (expressed in weight) in sub-Saharan Africa. Due to data gaps and

resource constraints, APHLIS extrapolates data points (mostly estimates provided by experts) to other time periods, crops and regions. For this reason, the analysis in [Figure 6](#) excludes APHLIS data.

The complexity of collecting food loss data explains why only 39 countries have officially reported loss data between 1990 and 2017 through FAO's *Questionnaire on Crop and Livestock Production and Utilization*.⁷² Hence, the FLI includes both data provided by governments and data produced by NGOs, academia and other institutions upon which the findings of the meta-analysis are based (e.g. case studies, surveys, research, etc.). [Figure 9](#) shows a heat map of the availability of food loss data for various regions and product groups. [Figure 9A](#) shows that governments in Latin America and the Caribbean have reported more data since 1990 than those in other regions (mostly for fruits and vegetables), followed by Northern America and Europe. Official data from the other regions are scarcer. [Figure 9B](#) shows that most non-governmental studies concern countries in Central and Southern Asia, in particular for fruits and vegetables.

Note that all official reports by governments cover entire food supply chains up to, but excluding, the retail and consumption stages, whereas non-governmental studies are often restricted to a particular stage or activity within the food supply chain. As a result, there are more non-governmental studies. Note that non-governmental studies often employ different methodologies to estimate food loss and waste, even studies within the same country; they cannot therefore be a substitute for the comprehensive collection of data carried out by national governments.

Estimating how much food consumers waste is particularly challenging, for two reasons. First, in surveys and studies based on self-reporting, consumers often underestimate the amount of food they actually waste.^{5,73} A combination of a survey with a sample analysis produces the most reliable results, but is much more costly.^{74,75} Second, municipal waste measured in many countries includes both food and non-food waste. Estimating how much of that total is food

(waste compositional analysis) has proved to be highly complex, expensive and sometimes impossible. Due to these complexities, there is no general agreement on what constitutes the most appropriate method to measure consumer food waste; this (partly) explains the scarcity of data on the amount of food wasted at consumption.

FAO has worked towards harmonizing concepts related to food loss and waste, both internally and with external partners. There is a consensus on definitions of food loss and food waste which will help overcome the existing data gaps (see [Boxes 1](#) and [2](#) for a detailed description of concepts related to food loss and waste). FAO has also formulated guidelines for measuring food loss, to assist countries in their official reporting (see the measurement guidelines developed by the *Global Strategy to Improve Agricultural and Rural Statistics*).⁷¹ Through a multi-stakeholder partnership, the Food Loss and Waste Protocol has published the *Food Loss and Waste Accounting and Reporting Standard* to harmonize data collection.⁷⁶ The Food Waste Index (FWI), currently under development under the auspices of UN Environment, is an important step towards the better measurement and understanding of food waste.⁷⁷

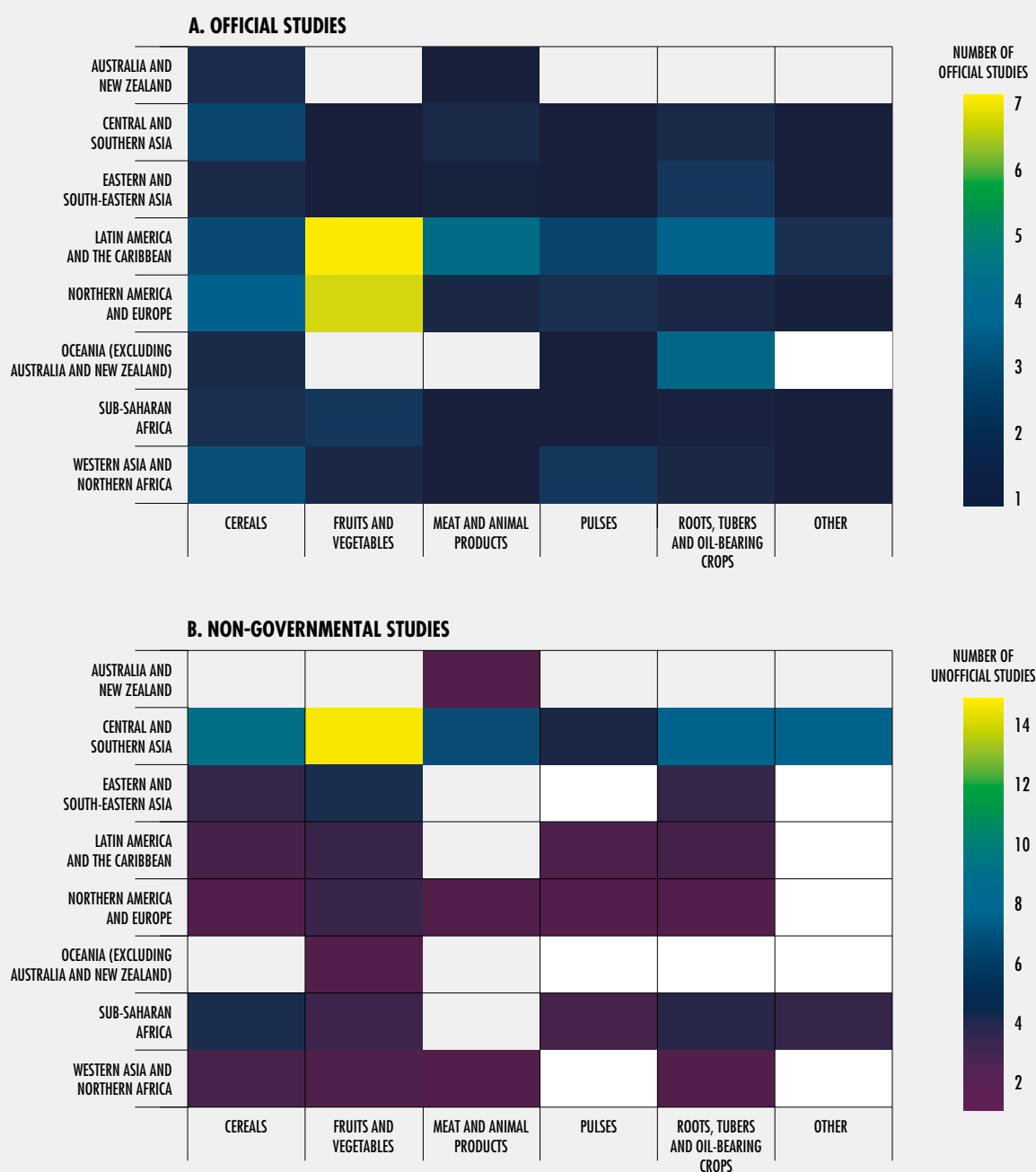
Chapter 6 provides a deeper discussion of efforts to improve data collection and also offers recommendations for food loss and waste measurement. ■

CONCLUSIONS

A first estimate of overall food loss by FAO throughout this report concludes that globally 13.8 percent of all food is lost from post-harvest up to, but excluding, retail. While this estimate helps to draw attention to the problem and incite action, effective interventions to reduce food loss and waste must be based on more detailed information regarding where it occurs in the food supply chain; for which foods and in which regions or countries it occurs; and the extent of the problem and underlying reasons.

FAO's meta-analysis of existing studies of food loss and waste presented in this chapter provides further insight into these aspects. However, the »

FIGURE 9
HEAT MAP OF FOOD LOSS STUDIES BY REGION, 1990–2017



NOTE: Official studies comprise countries' Annual Agriculture Production Questionnaires, which are officially reported to FAO. Non-governmental studies include research, surveys and case studies by NGOs and institutions (including academia). The heat maps assign colours to regions based on the number of estimates of food losses reported for that region between 1990 and 2017, for various product groups. White boxes indicate that no data are available for that product group in that region. Each region was standardized by the number of countries, so that regions with fewer countries would not automatically have a lighter colour.

SOURCE: A. FAO, 2019⁷²; B. FAO, 2019²

- » studies included in the meta-analysis are not necessarily methodologically consistent, and considerable data gaps remain. Therefore, the analysis is limited by the lack of comprehensive, comparable and reliable data. More precise, context-specific studies of individual supply chains are required to inform targeted interventions to reduce food loss and waste. Case studies that use FAO's standard methodology to identify critical loss points represent a step in this direction.

Overall, significant work has been carried out to measure food loss and waste; however, the possible causes of food loss and waste are numerous and highly dependent on the

socio-economic and cultural context in which actors in the food chain operate. As a result, they vary greatly from one region or country to the next. There is a significant amount of knowledge that can be tapped, but the fact remains that data are scarce, scattered, of unknown quality or limited representativeness. One cannot sufficiently emphasize the need to improve the evidence base and urgently overcome the challenges for data collection to form effective solutions towards reducing food loss or waste. This, however, requires substantial research efforts (and thus financial investments) from both public and private actors at international and national levels. ■

EGYPT

A young labourer
loading tomatoes onto
wholesalers' trucks.

©FAO/Heba Khamis



CHAPTER 3

REDUCING FOOD LOSS AND WASTE – THE BUSINESS CASE AND BEYOND

Key messages

1 The business case for food loss and waste reduction is based on the assumption that food suppliers can increase their profits by reducing food losses and that consumers save money by wasting less.

2 The limited evidence to date suggests that the business case can potentially increase profits and lead to certain reductions in food loss or waste; however, focusing on the business case alone is unlikely to address the full scale of the problem.

3 Even in those cases where interventions to reduce food loss and waste are not profitable, reduction efforts may result in productivity gains that represent an economic benefit to society at large. Such economic cases may justify public-sector intervention.

4 Policymakers should weigh the potential benefits of food loss and waste reduction efforts not only against their costs, but also considering the distributional implications for incomes and the well-being of the different actors in the food supply chain.

5 Public interventions may take the form of awareness raising campaigns aimed at convincing individuals of the benefits they receive from food loss or waste reduction.

6 Other interventions may aim to improve the incentives offered to suppliers and consumers to reduce food loss or waste, through investments, taxes, subsidies or regulation.

REDUCING FOOD LOSS AND WASTE – THE BUSINESS CASE AND BEYOND

This chapter examines to what extent the private sector can be relied on to reduce food loss or waste, and the scope for public-sector intervention. Where the benefits of food loss and waste reductions accrue to stakeholders other than those implementing the reduction measures, public intervention may be justified. The chapter looks at the net benefits of food loss and waste reduction for private actors (the **business case**) and then discusses the broad economic benefits of these reductions for society as a whole (the **economic case**). The economic case looks beyond the business case for food loss and waste reduction, to possible gains for society at large that private actors do not take into account. If these society-wide gains exceed the costs of efforts towards loss and waste reduction, public intervention may be justified. ■

THE PRIVATE AND SOCIETAL BENEFITS AND COSTS FROM REDUCING FOOD LOSS AND WASTE

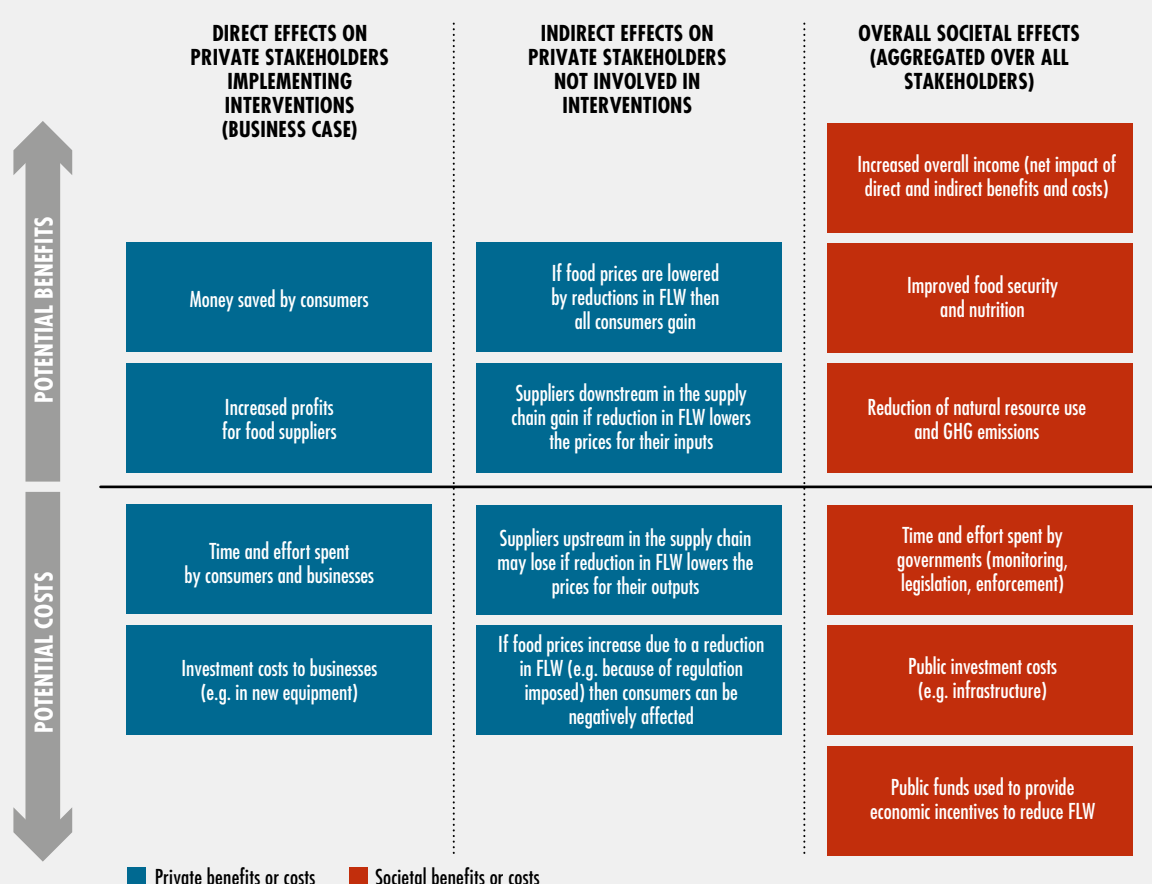
Figure 10 lays out the potential benefits and costs of food loss and waste reduction, and distinguishes between those costs and benefits that accrue to private stakeholders (blue boxes) and broader costs and benefits to society (red boxes). The figure also distinguishes between the benefits and costs of private stakeholders directly involved in reducing food loss and waste versus those of private stakeholders who are affected indirectly through changes in prices associated with reductions in food loss and waste. For private stakeholders involved in interventions, costs and benefits are those associated directly with the intervention.

For the indirect effects, changes in prices along the supply chain will depend on where interventions are occurring, and will affect private stakeholders differently depending on whether the stakeholders are upstream or downstream in the supply chain relative to where the price change occurs. Actors operating at earlier stages in the food supply chain will see it as a change in the price of their food product, while stakeholders at later stages in the food supply will see it as a change in their input costs. This indicates that there may be winners and losers among private stakeholders. For example, if food waste at the retail level is reduced, wholesale suppliers may see a decrease in demand that negatively affects their returns, but at the same time the reduction in retail waste may make food cheaper for consumers, which increases their well-being.

To examine whether society-wide gains exceed the costs of efforts towards loss and waste reduction, Figure 10 aggregates the net benefits for private stakeholders – both direct and indirect – and then factors in the impacts on the environment and on food security and nutrition as additional benefits. These three sets of benefits, assuming they are ultimately positive, then need to be weighed against the costs incurred by society as a whole to attain the reductions in food loss and waste. These costs will be those incurred by the public sector for enabling the reductions (private benefits and costs are already considered in the “increase overall income” box in Figure 10).

In this chapter, the economic benefits considered for the economic case are limited to those linked to monetary transactions. Thus, the economic benefits of food loss and waste reduction are seen in terms of the resulting increase in productivity, which boosts the well-being of

FIGURE 10
POTENTIAL PRIVATE AND BROADER SOCIETAL BENEFITS AND COSTS OF FOOD LOSS AND WASTE (FLW) REDUCTION



SOURCE: FAO

society as a whole. This narrow definition of economic benefits excludes any positive impact of food loss and waste reduction on food security and nutrition. It also disregards how reduction efforts may mitigate the negative impact of food loss and waste on the environment, in terms of GHG emissions and pressure on land and water resources. Indeed, the impact of food loss and waste reduction on food security and nutrition

and environmental sustainability is much harder to express in monetary terms. These two important dimensions are therefore discussed separately in Chapters 4 and 5.

To sum up, this chapter, in combination with Chapters 4 and 5, makes an incremental argument for reducing food loss and waste. It starts by looking at the business case for food

loss and waste reduction (just direct effects, first column in Figure 10) as justification for reducing food loss and waste. It then moves on to the economic case as a justification to intervene on food loss and waste, accounting for direct and indirect net economic benefits on private stakeholders (represented by the “increase overall income” box in Figure 10, which combines the first two columns in the figure) to be balanced with whatever public costs are incurred to attain the reductions (bottom half of third column in Figure 10). The economic case, as covered here, does not take into consideration the environmental and food security and nutrition benefits of decreasing food loss and waste. This is done in the following chapters, which examine the additional benefits of reduction of food loss and waste in terms of food security and nutrition (Chapter 4) and the environment (Chapter 5). ■

THE BUSINESS CASE FOR REDUCING FOOD LOSS AND WASTE – OPPORTUNITIES, COSTS AND BARRIERS

Food loss and waste reduction can benefit the private sector but there are barriers to adoption

As argued in Chapter 1, in theory, participants in the food supply chain make rational decisions that allow them to maximize their profits (suppliers) or well-being (consumers) – including decisions on the level of food loss or waste they find acceptable. Food loss and waste reductions can have a positive impact upon suppliers’ and consumers’ well-being.

- Food suppliers, for example farmers, processors, transporters, retailers and food service providers, can increase their productivity by reducing food loss and waste. Indeed, if less food is lost or wasted, suppliers have more food to sell using the same amount

of inputs while costs related to disposing of lost or wasted food decrease.^{1,2} Suppliers who work to reduce food loss and waste may improve their reputation for environmental stewardship and strengthen customer relations.¹

- Consumers who reduce their food waste save money to spend elsewhere; they may also benefit from lower food prices if food loss reductions by suppliers make food cheaper at wholesale and retail levels. But this depends on how the price effects of food loss reductions ripple through the chain, which in turn is determined by where the reductions occur and how large they are.¹ Consumers may fulfill a moral, rather than financial, objective by reducing their food waste and thus limiting its negative environmental and social effects.

However, efforts to reduce food loss and waste involve costs, which rational individuals will only be willing to bear as long as the benefits that accrue to them outweigh such costs. By this view, a certain level of food  or waste is unavoidable, depending  on the technology available to suppliers and consumers, as well as the perishability, distribution systems and consumption patterns for food products.

For example, if the opportunity cost of time for consumers is high, efforts to plan food purchases and meal preparation better and to manage food stocks (an effective strategy to reduce food waste) may be too time-consuming – in other words, costly – to make them worthwhile.³

Likewise, food suppliers may view the beneficial impact of reducing food losses by investing in technology or improved practices as too small in relation to the investment costs. For example, farmers might reduce on-farm losses of crops to pests or any natural hazard by improving storage and handling (e.g. by using hermetic grain storage bags), but if the costs exceed the value of the food that can be saved, they are unlikely to take

¹ Note that efforts by consumers to reduce food waste by buying smaller packages may result in a rise in their food spending, as smaller packages are often more expensive per unit of food bought.

such actions. The limited adoption of food loss reduction measures by maize producers in the United Republic of Tanzania (see **Box 13**) is a case in point. The same applies to efforts by food processors (e.g. optimizing the manufacturing process), retailers or food service providers (e.g. improving inventory management, adjusting packaging and labelling to discourage consumers wasting food, or redistributing excess food), as well as efforts that concern all operators in the chain, such as systems to track food losses. It follows that food supply chain operators devote more time and money to reducing losses and waste of food products with a high price value. Products that fetch lower prices may not warrant costly prevention measures, and operators may decide to compensate for such losses or waste by producing or buying in more.^m

However, a number of factors may prevent stakeholders from taking fully rational decisions as to the optimal level of food loss or waste, and thus optimizing their profits or well-being. First, food operators and consumers may not have full information on how much food they lose or waste, on how it affects them, on all the factors that combine to influence food loss and waste, or on the benefits and costs of reducing food loss and waste. These aspects are crucial to rational decision-making but they are also complex, and operators and consumers may not fully understand them. Second, suppliers and consumers may be very uncertain about the benefits of efforts to reduce food loss or waste, deterring risk-averse stakeholders from reducing food loss or waste. This uncertainty was cited as one of the reasons for the limited adoption of such measures by maize producers in the United Republic of Tanzania (see **Box 13**).⁵

The financial cost–benefit analysis of efforts to reduce food loss and waste by individual economic players is determined by the private and social context in which they operate,

^m Note that the price value of a food product differs not only from one type of food to the next, but also between the various stages in the supply chain, for the same product. The value of a tomato, for example, is higher at the retail level than at the farm level. By the time the tomato reaches the supermarket, more resources have been used to get it there (transport, fuel, energy for storage, the costs of running the retail outlet, etc.).⁴

including, for example, the financial and physical resources available to them at private and public levels. Thus, even if they are aware of the problem of food loss or waste and the actions that could help mitigate the problem, various types of constraints may discourage them from taking such actions. For example, individuals in developing countries, especially smallholders, often cannot afford the high upfront costs associated with food loss and waste reduction efforts without financial help. Yet, credit providers already consider agriculture as a high-risk sector and payback periods are often challenging for farmers with immediate cash needs.⁶ Thus, access to credit becomes a barrier to adopting food loss and waste reduction measures.

A 2011 study by the World Bank shows that in sub-Saharan Africa there is a variety of practices and technologies to reduce post-harvest losses of food. However, they are rarely adopted and efforts towards change have failed for a number of reasons. Some technology packages transferred from Asia proved financially unsustainable in the context of Africa. Some interventions did not identify the key constraints, or assumed wrongly there were economic incentives for reducing losses. Some technologies were not culturally acceptable (e.g. metal silos were a success in Central America but not so in Africa, *inter alia* due to a preference for storing foods inside the home to prevent theft). Other interventions to facilitate change were hampered by unrealistic timeframes.⁷

Even so, successful cases do exist. Examples of such in Asia and Africa often relate to adopting improved technology (such as small-scale dryers, threshers and storage bags) for post-harvest rice handling and storage. Successful examples are linked to strong government support, e.g. through financial incentives to early adopters or creating an enabling environment for infant industries. **Box 14** provides an example of an alternative storage method that led to a reduction in post-harvest losses.⁷ The size of operations matters: larger operations can shoulder costlier investments. For example, a study in Uganda found that plastic silos are financially viable »

BOX 13

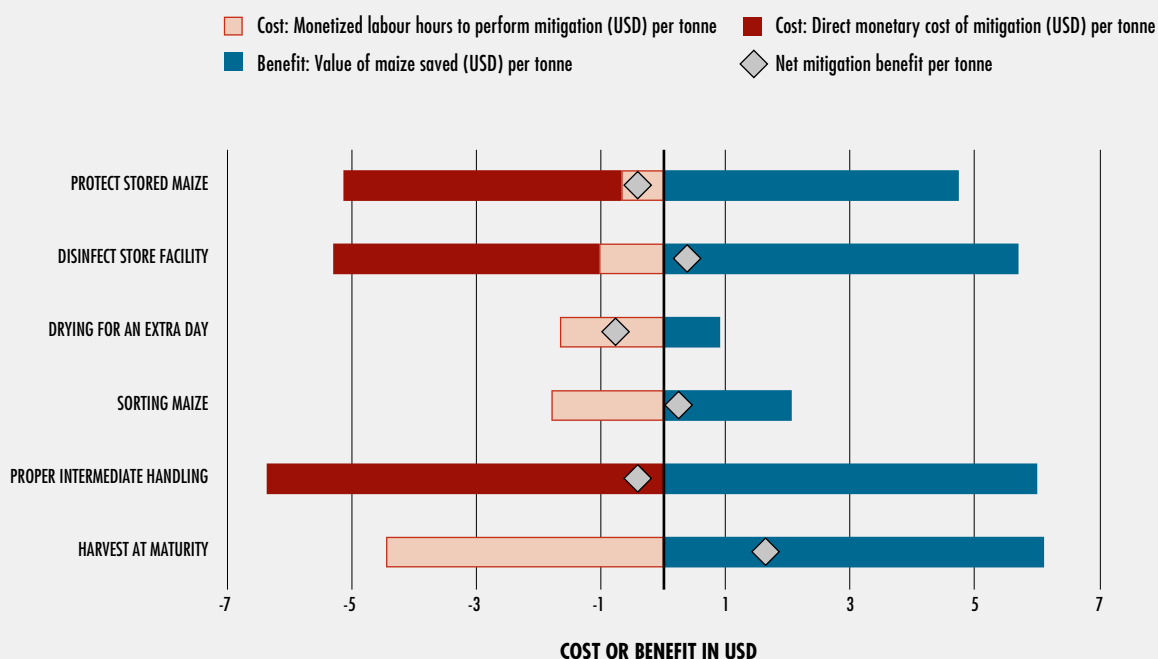
A FINANCIAL COST–BENEFIT ANALYSIS OF POST-HARVEST LOSS REDUCTION FOR MAIZE IN THE UNITED REPUBLIC OF TANZANIA

A 2018 survey of 420 households producing maize in a rural district in the United Republic of Tanzania examined to what extent improved post-harvest handling can reduce food losses.

The survey found that, on average, post-harvest losses account for 11.7 percent of households' annual maize harvests, representing a value of USD 58.9 (1.2 times the median monthly household income). On average, 2.9 percent of the harvest was lost during pre-storage stages, 7.8 percent during storage and 1 percent during marketing.

The study confirms that improved post-harvest handling can significantly reduce losses. A financial cost–benefit analysis of various post-harvest practices (see the figure below) shows that not all practices aimed at reducing losses are beneficial. While the benefits of timely harvesting, sorting maize and disinfecting storage facilities outweigh the costs, other practices such as proper intermediate handling, protecting stored maize and letting the maize dry for an extra day are not financially worthwhile.

FINANCIAL COST–BENEFIT ANALYSIS OF PRACTICES AIMED AT REDUCING POST-HARVEST LOSSES OF MAIZE IN THE UNITED REPUBLIC OF TANZANIA



SOURCE: Chegere, 2018, Table 6⁵

BOX 14 PROMOTING MUD SILOS TO REDUCE MAIZE LOSSES DURING STORAGE – EVIDENCE FROM NORTHERN GHANA

Mud silos seal well and are therefore a better option to store food grains than other, more open types of storage. In 2000, the Ministry of Food and Agriculture of Ghana, in collaboration with partners, implemented a wide-ranging programme to promote the use of mud silos for maize storage in the Northern Region of Ghana – the aim was to encourage smallholders to use these silos over other more traditional types of storage.

Under the programme, funded by the United States Agency for International Development, artisans from communities that use mud silos demonstrated their construction in selected villages in six districts of northern Ghana. The demonstrations were facilitated by the fact that communities who traditionally use mud silos live close to those who do not.

More than 1 000 farmers in the Gushegu and Karaga Districts in the Northern Region of Ghana started using sealed mud silos as a result of the programme, and a survey of 60 farming families evaluated its success. All 60 families owned both mud silos and other types of storage facilities and most of those surveyed were using the mud silos at the time. As a result, maize storage losses dropped from an average 300 kg per family per year to about 50 kg. Of all maize damaged by insects while in storage, an average 6.5 percent occurred inside the mud silos. The remaining 93.5 percent of losses occurred in other facilities.

With the costs of construction in Ghana estimated at less than USD 10⁹ and less labour needed to maintain them than other types of storage, mud silos were shown to offer a low-cost solution to store and protect grain.

SOURCE: World Bank, 2011⁷

- » only for farmers who have an above-average acreage; options that are affordable for smaller farms, such as hermetic bags, were financially unattractive in terms of net benefits generated.⁸

Quantifying the financial gains of food loss and waste reduction for suppliers and consumers

A study of households producing maize in the United Republic of Tanzania confirms that improved post-harvest handling can significantly reduce losses (see [Box 13](#)); however, not all practices aimed at reducing losses are financially beneficial. The study shows that identifying the best entry points for post-harvest interventions and assessing their financial feasibility for smallholders is crucial to success.

A 2017 study by the World Resources Institute (WRI) and the Waste and Resources Action Programme (WRAP) found there can be a strong financial business case for companies to pursue efforts to reduce food loss and waste ([Box 15](#)). Note that the study only looked at the financial impact on the operator implementing the measures and not the effects of the measures on other actors in the food supply chain, whether upstream, such as farmers, or downstream. Farmers' products may fetch lower prices, for example, if buyers need fewer inputs as a result of food loss reduction. Farmers may also be forced to discard more products if their clients impose stricter quality standards to reduce food losses. Such redistributive effects are further discussed in this chapter.

A study by Rethink Food Waste (ReFED), a multi-stakeholder non-profit platform

BOX 15

THE BUSINESS CASE FOR REDUCING FOOD LOSS AND WASTE – A SURVEY BY CHAMPIONS 12.3

Food operators have an incentive to implement measures to reduce food loss and waste if the financial benefits of doing so outweigh the costs. A recent report by the WRI and WRAP on behalf of Champions 12.3, a coalition of international leaders dedicated to accelerating progress towards achieving SDG Target 12.3, studies the financial case for food loss and waste reduction, analysing nearly 1 200 business sites in 17 developed and developing countries. It was found that more than 99 percent of the sites earned a positive return on investment in food loss reduction; the median site realized a 14-fold financial return on its investment (sites closer to the consumption stage of the food supply chain tended to have higher median ratios than those closer to the production stage). Such a

high return indicates there can be a strong financial business case for companies to reduce food loss and waste.

The report cites the example of a food manufacturer in Pakistan who pursued a number of actions to reduce food losses, including improved cooling and storage, strengthening dairy farmer training and best practice sharing and implementing lean management processes. These efforts resulted in a 25 percent return on investment for the company. Another example is that of a food services provider in western Europe whose waste reduction efforts – such as using more semi-prepared food, improving meal demand forecasting, training staff and engaging consumers – had a benefit–cost ratio of nearly 25:1.

SOURCE: Hanson and Mitchell, 2017¹

bringing together businesses, NGOs and the government aimed at reducing food waste in the United States of America, estimates that businesses can potentially increase their annual profits by implementing a number of food loss prevention and recycling solutions (see Box 16). ■

THE ECONOMIC CASE FOR REDUCING FOOD LOSS AND WASTE – FROM PRIVATE TO PUBLIC INTEREST

Food loss and waste reduction benefits not only private actors involved in the process, but also society as a whole

The previous section argued that reducing food loss and waste may have a positive impact on suppliers' profits and consumers' well-being. However, the financial incentives (the business case) for private stakeholders to reduce their food losses or waste may be weak. Even where the business case for food loss or waste reduction is clear, stakeholders may be unable to implement the necessary actions because of financial constraints. »

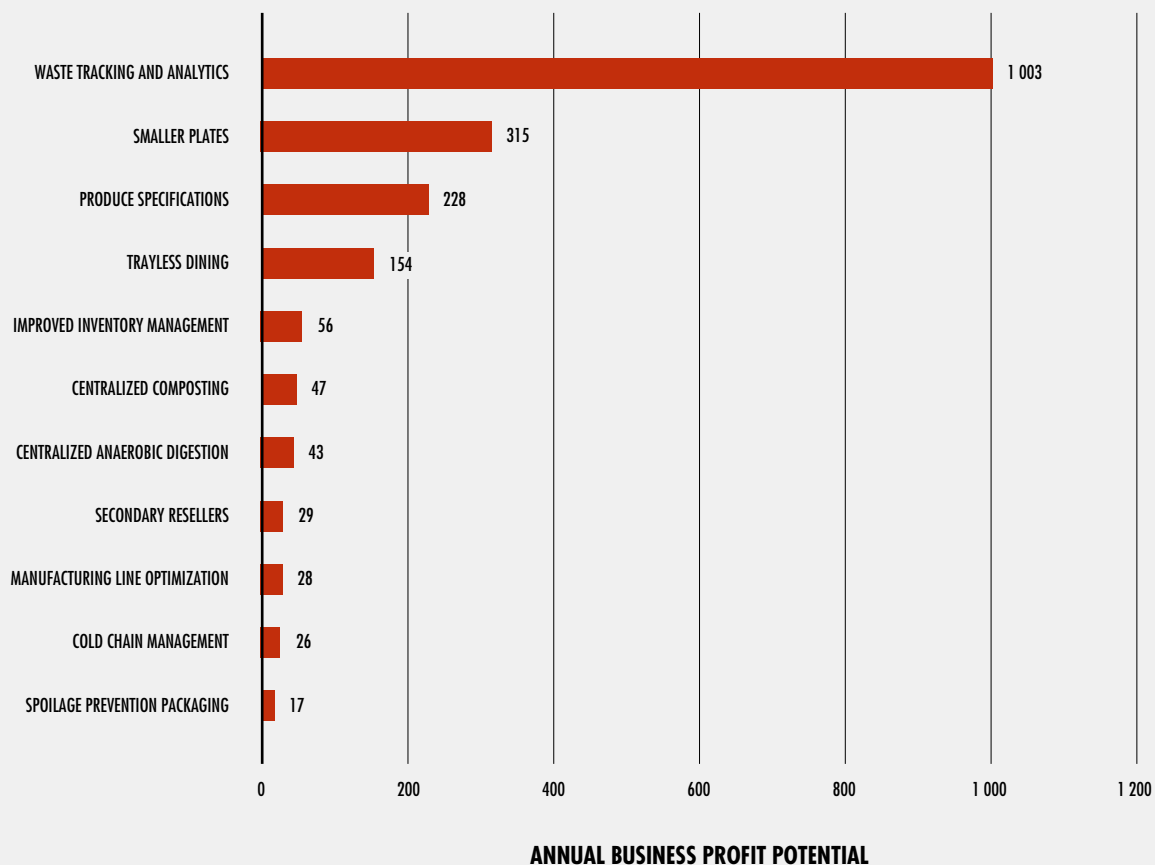
BOX 16

THE BUSINESS CASE FOR REDUCING FOOD LOSS AND WASTE – A STUDY BY REFED

ReFED analysed 27 possible solutions to food loss and waste in the United States of America, grouped into three categories: prevention, recovery (redistribution) and recycling. It estimates that businesses can potentially increase their profits by USD 1.9 billion annually by implementing nine prevention and two recycling solutions. Of this total, USD 1.6 billion would accrue to food service providers, including restaurants. Most of the total profit opportunity comes from waste tracking and analytics, reflecting the operational

inefficiencies that exist today in food purchasing and preparation. One of the reasons why restaurants fail to adopt the solutions identified in the report is the gap in employee training caused by high turnover rates and competing priorities such as food safety and food quality. Other promising strategies include smaller plates in food service outlets, using imperfect produce in food preparation and marketing imperfect produce as a new product line.

ESTIMATED ECONOMY-WIDE ANNUAL BUSINESS PROFIT POTENTIAL OF SELECTED FOOD WASTE SOLUTIONS (USD MILLION)



SOURCE: ReFED, 2016, p. 23¹⁰

» The economic case for food loss and waste reduction looks beyond the business case to include gains for society at large, which private stakeholders may not necessarily take into account. This broader case is built on three ways in which reductions can boost societal well-being. First, food loss and waste reduction may improve productivity and thus contribute to economic growth. Such economic growth benefits not only private actors, but also society as a whole. Second, food loss and waste reduction may improve the food security or nutrition status of the most food insecure. Third, it may help mitigate the negative environmental impacts of food loss and waste in terms of GHG emissions and pressure on land and water resources. This chapter focuses on the first pillar of the economic case and examines how food loss and waste reductions can generate positive economic outcomes for society. The other two main arguments for reduction – improvements in food security and nutrition and environmental sustainability – are the focus of Chapters 4 and 5.

An additional argument for the broader economic case for food loss and waste reduction is the fact that reduction efforts, such as the adoption of improved food redistribution practices, can contribute to indirect job creation. In 2014, Massachusetts, in the United States of America, modified its existing waste ban regulation, the Commercial Food Waste Disposal Ban, to add food to the list of materials banned from disposal. Under the modified regulation, food companies and institutions are not allowed to dispose of more than 1 ton of commercial organic material per week. Any waste over that limit must be diverted, for example by donating it to charity or sending it to be turned into animal feed, composted or anaerobically digested. Probably as a result of the new regulation, both food rescue organizations and the organic waste industry experienced significant growth between 2010 and 2016, with a considerable increase in the number of jobs. The amount of food received annually by the average food rescue organization increased from 37 tons in 2010 to 193 tons in 2015. The growth of food rescue organizations has generated over USD 460 000 in annual state and local tax revenues.¹¹ One limitation of the ban's economic impact analysis worth mentioning is that the baseline year (2010)

was four years before the ban was amended to include food waste – therefore the results may be overestimated.

Quantifying the economic gains of food loss and waste reduction for society at large

Attempts to quantify the costs of food loss and waste (such as the WRAP study) have so far been mainly based on calculation of the amount of food lost or wasted in food prices (wholesale or retail). This can mistakenly deliver the message that reduced food loss and waste will automatically translate into gains for society of the same amount.^{12–14} Although estimates in price terms do provide useful indications as to the scale of the food loss and waste problem, they fail to take due account of the way in which price signals are transmitted throughout the food supply chain or the wider national and global economy, as well as of the distributional effects thereof. Furthermore, a significant strand of literature examines the impact of interventions in food loss and waste reduction without considering their costs.^a Economic cost–benefit analyses should take these costs into account.^{15–17} In general, estimating the costs of efforts towards food loss and waste reduction, which involve specific, identifiable investments, seems easier than estimating their benefits.²

The analysis of the economic gains of food loss and waste reduction should take due account of the fact that those who bear the costs of such efforts are not necessarily the ones who enjoy the benefits. Whether suppliers and consumers voluntarily implement measures towards lower food loss and waste, or whether such measures are imposed through legislation, can provide an indication of who wins or loses from food loss and waste reduction.² The rationale is that stakeholders will voluntarily reduce food loss and waste if the benefits of doing so outweigh the costs. In the absence of a business case, implementation may be mandatory through regulation. For example, legislation that obliges retailers to modify product labels with a view to reducing food waste (by better use of terms such as “best before” or “use by”) may benefit

^a E.g. Rutten and Kavallari.¹⁵

consumers by helping them avoid food waste. However, retailers bear the costs of altering labels. On the other hand, where measures to reduce food loss or waste are voluntary, they are likely to bring net gains to food operators. Thus, to reduce waste a retailer may decide to sell imperfect produce as a new product line (often marketed as “ugly” fruits and vegetables) if the benefits, including the revenue from selling previously unsellable products and acquiring a higher reputational standing, outweigh the costs of transporting and distributing the additional products. Also, suppliers may prevent produce loss and improve consumer access to safe and affordable food through efficient trade. This may also offer opportunities for food providers to sell products that are not commonly consumed where they are produced.¹⁸

An exhaustive study by ReFED for the United States of America finds that solutions with considerable economic value *and* those which are profitable for businesses can reduce losses and waste by approximately 2 million tons. This amount represents 4 percent of the total amount of food sent to landfill or incinerators prior to implementation of reduction efforts, as estimated by ReFED. However, the wider economic cost–benefit analysis of reduction efforts by ReFED suggests that up to 20 percent of food losses and waste can be avoided (see [Box 17](#)).

The results of the ReFED study cannot be generalized across countries, and the analysis may fail to consider certain solutions. Nevertheless, the findings of the study suggest that efforts implemented by private stakeholders based on pure business considerations alone are unlikely to resolve the food loss and waste problem. Even while acknowledging wider economic benefits (without taking into account the effects of loss reduction on job creation, food security or the environment, see [Box 18](#)), major reductions seem unlikely. Thus, the public sector has an important role to play in achieving SDG Target 12.3, through investments, taxes, subsidies or regulations. ■

WINNERS AND LOSERS IN FOOD LOSS AND WASTE REDUCTION

Actions to reduce food loss or waste can depend on different actors, according to the type of food loss or waste targeted. Those who bear the costs of food loss or waste reduction are not necessarily the ones who enjoy its benefits. Indeed, the impact of efforts to reduce food loss and waste on farmers, processors, distributors, retailers and consumers depends on how the effect on prices is transmitted throughout the food supply chain. Some may well benefit while others may lose.

As explained in the beginning of the chapter, food suppliers who increase their productivity by reducing food losses may see their profits grow. Losing less food means producing more, using the same amount of resources, while costs related to disposal decrease. However, the increased food supply may cause prices to fall, which would nullify the positive effect of increased sales. The net effect on overall profits depends *inter alia* on the flexibility of prices, the price elasticity of supply and demand, and on how price effects are transmitted from one stage of the food supply chain to the next.

Consumers who reduce their food waste save money to spend elsewhere. If food loss reductions by suppliers make food cheaper for consumers, the latter may benefit from an increase in their effective income (their income after food spending), or from the fact they can now purchase more food for the same amount of money. However, increased productivity resulting from food loss reduction may reduce the demand for labour and depress wages, which would work against the positive effect of a fall in food prices on household income. The combined net effect of lower food prices versus lower wages on a household’s income depends *inter alia* on the share of labour in overall production costs, wage flexibility, the sector in which household members are employed, the share of food spending in overall household expenditure and the price elasticity of supply and demand. Note that as food becomes cheaper, the incentives for consumers to avoid food waste may weaken. »

BOX 17

QUANTIFYING THE ECONOMIC GAINS OF FOOD LOSS AND WASTE REDUCTION – THE REFED STUDY

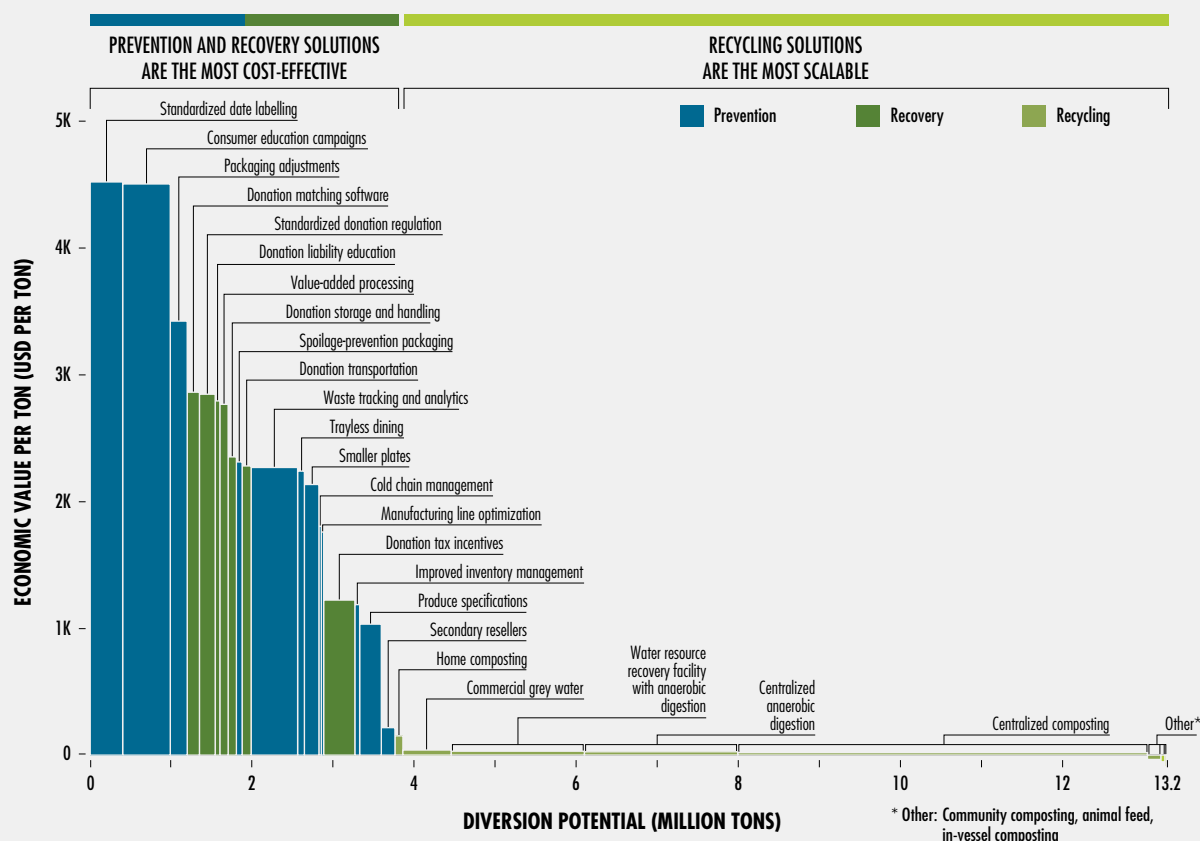
A recent study by ReFED (see also [Box 16](#)) analysed not only the financial value to businesses, but also the economic value to society, of 27 measures aimed at reducing food loss and waste, whereby economic value was defined as the aggregate financial benefit to society (consumers, businesses, governments and other stakeholders) minus all investments and costs over ten years.

Note that the definition of economic value as used by ReFED includes financial benefits enjoyed by all actors in society and excludes the non-financial impacts of food loss and waste reduction on society. Specifically, the non-financial benefits not considered in the study are those related to food security (meals recovered), job creation, and environmental gains (GHG reductions and water conservation).

The figure below displays the marginal abatement cost curve per ton of reducing food waste in USD. The width of each bar represents the annual diversion potential for each solution, measured in tons of waste reduced.

The study finds that the 27 selected solutions have the potential to generate USD 100 billion over ten years, considerably higher than the approximately USD 19 billion in business profits over the same period (see [Box 16](#)). Prevention solutions account for over 75 percent of this total; 23 percent is generated by recovery and 2 percent by recycling. Prevention and recovery solutions generally result in greater economic value per ton, while recycling solutions have the potential to divert a significantly larger volume of lost or wasted food.

MARGINAL FOOD WASTE ABATEMENT COST CURVE FOR THE UNITED STATES OF AMERICA



SOURCE: ReFED, 2016, p. 20¹⁰

BOX 17
(CONTINUED)

The solutions that generate the greatest economic value per ton are standardized date labelling, consumer education campaigns and packaging adjustments, all of which are measures aimed at prevention, rather than diversion. Meanwhile, centralized composting and anaerobic digestion have the largest diversion potential in volume (these three measures can collectively reduce 9.5 million tons of waste annually, nearly three-quarters of the total potential), but their economic value per ton is low. The generally higher net economic value generated by prevention solutions reflects the fact that these solutions typically require relatively low investments, while most centralized recycling solutions require heavy investment in transportation and processing infrastructure.

Furthermore, the benefits reflect the value of food and food waste. Thus, the economic value of prevention solutions, which captures the value of edible food, with an average retail value of USD 5 000 per ton, is higher than that of recycling solutions, which capture the value of food scraps whose average value is less than USD 100 per ton.

The ReFED study finds that the solutions that potentially generate the highest economic value for society are not necessarily those that bring most financial benefits to businesses. Likewise the solutions that appeal most to businesses – waste tracking and analytics, smaller plates in food service outlets and using and marketing imperfect produce (see Box 16) – do not create most value for society.

» In developing countries, a sizeable amount of food is lost on the supply side of the food supply chain. A 2013 case study for Northern Africa and the Near East shows that efforts to reduce the amount of food lost by primary producers lowered unit production costs and increased food supply. Increased efficiency in production led to a fall in domestic prices which allowed households to buy more food for the same amount of money, resulting in higher food consumption levels and a lower dependence, and thus reduced vulnerability, to changes in world food markets. However, increased efficiency in primary production meant that less labour was needed to produce the same output, which caused a fall in employment and nominal wages. Overall, the combined net effect of these impacts was improved household food security and a decrease in rural poverty, as the positive effect of falling food prices on household purchasing power more than offset the negative impact of lower nominal wages.¹⁵

In developed countries, evidence indicates that food is lost or wasted mostly at the retail and consumption stages of the food supply chain and food waste reduction is high on the policy agenda. Efforts to reduce food loss and waste

generally focus on encouraging consumers to buy and thus waste less food.^{23, 24} If the fall in consumer spending on food implies that suppliers now sell less, or that their products fetch lower prices, the gains to society that accrue to consumers may be cancelled out by the decline in suppliers' profits. Also, consumers may decide to spend the money they saved in wasting less of product *a* by buying more of product *b*, or by buying a higher quality of product *a* (trading up), in which case there is a trade-off between the gains for suppliers of product *b* or of the higher-quality version of product *a* on the one hand and the losses for the suppliers of product *a* on the other.^{25, 26} Indeed, a study by WRAP found that while growing consumer awareness of food waste leads to a reduction in sales volume, sales revenue remains stable, suggesting that consumers trade up to higher-priced foods.²²

In conclusion, policymakers should not only weigh the potential benefits of efforts aimed at food loss and waste reduction against their costs in terms of both public and private funds, but also consider the distributional implications of such efforts on the profits and well-being of the various actors in the food supply chain. ■

PUBLIC-SECTOR INTERVENTION ON FOOD LOSS AND WASTE REDUCTION

The rationale for public intervention

The rationale for government interventions aimed at influencing decisions made by individual suppliers and consumers on food loss and waste is twofold.

First, the previous section argued that the financial incentives for private stakeholders to reduce their food losses or waste may be weak. Even where the business case for food loss or waste reduction is clear, individual stakeholders may be unable to implement the necessary actions because of financial constraints. Unless the public sector steps in and modifies the incentives for individual suppliers and consumers or helps them overcome these constraints, the potential for food loss and waste reduction to increase productivity or create jobs is lost and society as a whole loses out.⁹ The ReFED study provides an example of how addressing the full scale of food loss and waste by relying exclusively on the business case is unlikely to be successful in the United States of America.¹⁰

Second, the decisions of individual suppliers or consumers as to food loss and waste have negative implications on wider society that these individual actors do not take into account (known as negative externalities, see also Chapter 1). Indeed, even if losing or wasting a certain amount of food makes sense to individual suppliers or consumers in terms of maximizing their profits or well-being, they may ignore the fact that their decisions negatively affect the well-being of society at large. In other words, what is optimal from the perspective of an individual may be at odds with the best interests of society as a whole. These negative externalities of individual actors' food loss and waste

decisions are potentially significant, most notably in terms of food security and environmental sustainability – they thus provide a strong justification for public intervention, dealt with separately in Chapters 4 and 5.

Where there is a discrepancy between individual incentives and societal well-being, public interventions are needed to convince individual actors of the benefits that food loss or waste reduction can bring them (known as “nudging”), or to modify those incentives.

A further dimension that may warrant public intervention is that of gender imbalance, which can affect food loss and waste. If women face constraints in accessing and controlling the resources they need due to gender discrimination, there may be few incentives and/or possibilities for them to reduce food loss and waste. This can negatively affect efficiency throughout the food supply chain. Indeed, despite their important role in food supply chains, rural women often face specific constraints in accessing essential productive resources, services and information, and in participating in the decisions that may lead to food loss and waste reduction.²³ For example, rural women are often less involved than men in cooperatives and farmer organizations. As a result, these women have limited access to processing facilities, improved technologies and markets, which leads to greater food losses.

Public interventions in food loss and waste reduction can also be framed within a wider development agenda. For example, in developing countries with a high level of food insecurity or undernourishment, food loss and waste reduction is likely to be seen as a means towards improving food security and nutrition. If food loss and waste is then caused by a lack of infrastructure (e.g. poor-quality roads) or public services (e.g. an erratic electricity supply), government interventions to reduce food loss and waste by improving infrastructure or services can be embedded in a broader development strategy. Such a strategy will contribute to an enabling environment that encourages private stakeholders to invest in food loss and waste reduction.⁷ Market failures that result in food loss and waste may also warrant public intervention. For example, poorly functioning credit markets may mean that farmers

⁹ Given the high upfront costs involved in the research, development and implementation of new technologies aimed at reducing food losses or waste, government support is crucial, especially in the early stages.

BOX 18 THE “LOVE FOOD, HATE WASTE” CAMPAIGN

In 2007, the United Kingdom of Great Britain and Northern Ireland launched a nationwide initiative to reduce household food waste – within five years, it had achieved a 21 percent reduction. The basis of the initiative was the “Love Food, Hate Waste” radio, TV, print and online media campaign run by WRAP. The campaign raised awareness among consumers about how much food they waste, how it affects their household budget and what they can do about it. This initiative collaborated with food manufacturers and retailers to stimulate innovation, such as resealable packaging, shared meal planning and food storage tips.

The total implementation costs during the five-year period were estimated to be GBP 26 million incurred

by United Kingdom of Great Britain and Northern Ireland Government agencies, local authorities, food manufacturers and retailers. Households derived the majority of the benefits, thanks to the savings achieved by preventing food waste, estimated at GBP 6.5 billion. Local authorities also realized a substantial GBP 86 million worth of savings in food waste disposal costs. As for the private sector, benefits took the form of increased product shelf life and reduced product loss. While households started to consume more efficiently and companies may have experienced a decline in food sales, the companies affirmed that the non-financial benefits, such as strengthened consumer relationships, offset the costs.¹

cannot access funds to adopt loss-reducing production techniques; the abuse of market power by a buyer who is the only potential purchaser may depress the price paid to farmers, who then have fewer incentives to prevent losses.

Note that food loss and waste solutions that are appropriate in developed countries are not necessarily the best solutions in developing countries. In developed countries, most food is believed to be wasted at the retail and consumption stages of the food supply chain, while in developing countries, it is mainly lost in the earlier stages of the chain.^{19, 20} Thus, the solutions identified in the ReFED study, for example, rightly focus heavily on the consumer-facing side of the food supply chain: retailers and food service providers.¹⁰ In developing countries where post-harvest losses account for an important share of overall food loss and waste, efforts to promote improved growing and post-harvest technologies and practices might prove more effective in reducing food losses.

Nudging stakeholders towards an existing business case – opportunities and limitations

Individual suppliers or consumers may not be fully aware of how much food they lose or waste, what is causing food to be lost or wasted, how it affects them, or what the benefits and costs are of reducing food loss and waste. While the decisions made by one actor in the food supply chain may affect the use of resources further up or down the chain, individual players are often only partially aware of the decisions taken by others. As a result, their decisions are based on limited information and may well fail to maximize their profits or well-being. Surveys show that processors are often unaware of the magnitude of their food losses and consumers consistently underestimate how much food they waste.²⁴ In such cases, providing information to actors in the food supply chain may convince them of the business case for food loss and waste reduction.

Building awareness of food loss and waste may constitute a worthwhile strategy for the

BOX 19

PROVIDING INFORMATION AND TRAINING – THE CASE OF TOMATOES AND MILK IN RWANDA

FAO conducted a post-harvest loss analysis along two tomato supply chains and one milk supply chain in Rwanda using the methodology described in Box 12. In the tomato supply chains, critical loss points included sorting, grading, storage and transportation, with 30.3 percent of produce lost during these stages. In the milk supply chain, estimated losses of 36.5 percent mostly occurred at the farm, storage and transportation points.²⁵

Training in post-harvest handling and use of appropriate equipment can mitigate critical loss in the supply chains studied and, consequently, reduce the negative impact on food security and producers' incomes. While a subsequent cost-benefit analysis found all the proposed training methods were profitable for farmers, there were differences in profitability between them. In both tomato supply chains, training farmers in proper handling practices and using appropriate storage facilities had the highest benefit-cost ratios (from 4.7:1 to 1.9:1). The

most profitable solution for the milk supply chain involved training traders in proper milk collection, storage and transportation (a benefit-cost ratio of 2.1:1).²⁵

Since these are *ex ante* estimates of the impacts of any training, several caveats apply to the analysis. These include the extent to which the analysis considered all costs incurred by stakeholders and whether the estimated loss reductions would actually materialize. Nonetheless, the Rwandan case highlights how a cost-benefit analysis of interventions can provide insights into opportunities for the most effective food loss and waste reduction strategies across commodities and stages of the supply chain. This case study also sheds light on the importance and challenges of carrying out a rigorous cost-benefit analysis that separates social costs and benefits incurred by a project *vis-à-vis* the private benefits and costs that determine adoption beyond the scope of the intervention.

public sector to convince food supply chain stakeholders to reduce their food loss and waste. In the United Kingdom of Great Britain and Northern Ireland, the “Love Food, Hate Waste” awareness raising campaign by WRAP, an NGO specializing in resource sustainability, led to a 21 percent reduction in the amount of food wasted by households from 2007 to 2012 (see Box 18). Likewise, awareness raising campaigns in Denmark (spearheaded by the Stop Wasting Food movement, a private NGO) resulted in a food waste decrease of 25 percent from 2010 to 2015 (see also Chapter 6).

A reason why public awareness campaigns to promote food loss and waste reduction can be appealing to policymakers is that they generally entail low costs relative to the financial benefits. This premise is also supported by a recent FAO study on the supply chains for tomatoes and milk in Rwanda (Box 19), which shows that training

farmers could help them to avoid food losses at a relatively low cost to the public sector.²⁵

Nudging actors towards an existing business case for reducing food loss and waste is an attractive option because results can be obtained with limited financial resources by leveraging private stakeholders' interests. However, the broader studies reported in this chapter, such as ReFED (Boxes 16 and 17) and WRAP (Box 18), indicate that relying on the existing business case alone provides only part of the solution. The accomplishments of the WRAP initiative in reducing food waste by 21 percent over a specific time period are substantial, but they do not address nearly 80 percent of the problem. Moreover, the ReFED study in the United States of America finds that interventions that fall under the business case scenario would address only 4 percent of the total amount of food currently sent to landfill or incinerators.

The findings of these studies suggest that efforts by private actors based on business considerations alone are unlikely to resolve the food loss and waste problem. It follows that there may be a need to change the economic and legal landscape within which private actors make decisions about food loss and waste.

Changing the landscape for food loss and waste decisions – investment, incentives and regulation

Governments can work towards food loss and waste reduction by raising suppliers' and consumers' awareness of the benefits (making the business case) of any reduction. They can play an important role by modifying incentives to reduce food loss and waste (changing the business case). Or they can also make a significant contribution by addressing the indirect drivers of food loss and waste in ways that go beyond the business case. This is particularly important given how the upfront costs of investing in food loss and waste reduction can be significant and may discourage engagement by some smallholder businesses.

Alternative means of influencing decisions on food loss and waste reduction could include improving public services and infrastructure (for example, through public–private partnerships); issuing regulations that affect the decisions of individual actors regarding food loss and waste; or providing financial incentives for reduction through taxes, subsidies or exemptions. For example, the Government of the United States of America amended the Tax Reform Act in 2015 to give enhanced food donation tax deductions and permanently expanded it to all businesses, creating a stronger business case for food recovery.^{10, 26}

As argued in Chapter 1, the quality of public goods and services influences food supply chain actors' decisions on food loss and waste. However, given that they are public goods, private actors will not bear the full financial costs of providing them. This is where public–private partnerships – defined as cooperative ventures that involve at least one public and one private actor – can play a role (see **Box 20**).²⁷

As public awareness of food loss and waste grows, governments may issue regulations to address the problem. As part of an ambitious national strategy to tackle food waste in France in 2015, supermarkets with an area of 400 m² or more have been barred from throwing away food since 2016 and are obliged to enter into agreements to donate rejected food to charities. Other measures adopted under the national strategy include reducing food waste in schools and obliging food companies to include data on food losses in their social and environmental reports.²⁹

Donors have played a key role in promoting food loss and waste reduction in low-income countries. In sub-Saharan Africa, for example, institutions such as the Bill & Melinda Gates Foundation, the Rockefeller Foundation, the United States Agency for International Development, UK Aid, the World Bank, FAO and others have invested in the early stage development of technology aimed at reducing losses, such as hermetic bags for cereal storage, improved crates for transporting tomatoes and better fish processing technology.^{6, 30} ■

CONCLUSIONS

This report argues that, in theory, actors in the food supply chain make rational decisions to maximize their profit (suppliers) or well-being (consumers) – including decisions on the level of food loss or waste they can tolerate. In other words, rational actors will undertake efforts towards food loss and waste reduction only in as far as the benefits of those efforts outweigh the costs. In this view, a certain level of food loss or waste is unavoidable.

However, incomplete information about their own food loss and waste decisions, as well as those made by other actors in the food supply chain, may prevent actors from taking fully rational decisions on the optimal level of food loss or waste. This results in a loss of efficiency in the supply chain or reduced consumer well-being. Public interventions can convince suppliers and consumers of the business case for food loss and waste reduction, or allow »

BOX 20 PUBLIC–PRIVATE PARTNERSHIPS FOR FOOD LOSS AND WASTE REDUCTION IN APEC COUNTRIES

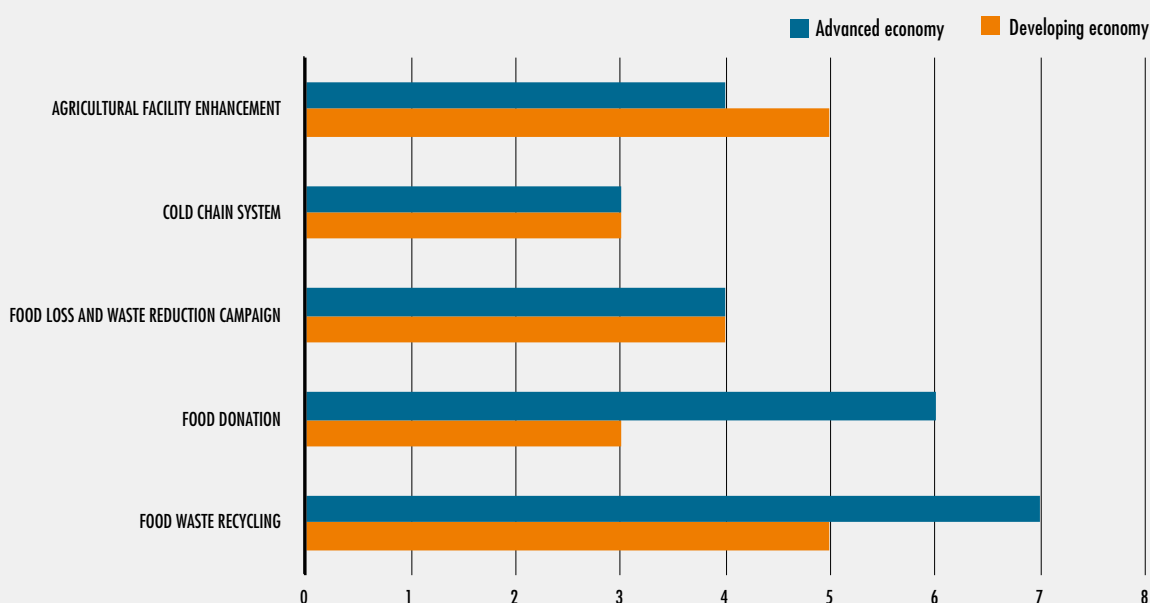
A survey undertaken by the Asia-Pacific Economic Cooperation (APEC) countries of public–private partnerships for food loss and waste reduction in the framework of a multi-year project (Strengthening Public–Private Partnership to Reduce Food Losses in the Supply Chain) found that most APEC countries have created several types of public–private partnerships. Two-thirds of all APEC governments provided public financial support in the form of loans, insurance or grants to businesses or non-profit organizations to implement measures aimed at reducing food loss or waste, making it the most widely used type of partnership. Other types of public–private partnerships include joint ventures involving both public and private equity; consultative partnerships relating to policy development and planning; contractual partnerships involving public procurement of financial and expertise services from private entities; and multifunctional partnerships, combining two or more of the above.

The figure in this box shows that most public–private partnerships focused on food waste recycling, in both developed and developing economies. Food donation ranked second, with two-thirds of interventions taking place in developed economies. Third was agricultural facility management, implemented predominantly in developing economies. The smallest number of public–private partnerships focused on improvements in cold chain systems.

APEC members identified knowledge sharing and improved policy and project performance as the most important advantages of public–private partnerships. All countries agreed that public–private partnerships enable resource saving and foster connections between stakeholders. Several countries stressed that linking multiple stakeholders improved the quality of data. APEC’s developing member economies strongly recommended that future public–private partnerships focus on agricultural facility management and cold chain systems.

SOURCE: APEC, 2018²⁷

TYPE OF INTERVENTIONS TOWARDS FOOD LOSS AND WASTE REDUCTION BY PUBLIC–PRIVATE PARTNERSHIPS IN APEC COUNTRIES (NUMBER OF PARTNERSHIPS)



NOTE: Eight advanced economies (Australia; Canada; China, Hong Kong SAR; Japan; New Zealand; Singapore; Taiwan Province of China; and the United States of America) and seven developing economies (Chile; China; Malaysia; Papua New Guinea; Peru; Philippines; and Viet Nam) are included in the 2018 survey, out of APEC’s 21 member economies. Period covered is not specified in survey question. Economies are classified as “advanced” or “developing” according to the International Monetary Fund (IMF) classification.²⁸

SOURCE: APEC, 2018, Figure 8²⁷

- » them to overcome financial or other barriers that stop them from making food loss and waste decisions that maximize their profits or well-being. The case studies presented in this chapter show that any significant reductions in food loss or waste will indeed require public interventions.

Looking beyond the business case for food loss and waste reduction, there are gains to be had from reducing food loss and waste for society at large that private stakeholders do not necessarily take into account. This broader economic case provides a justification for public interventions on food loss and waste reduction and is built on three pillars for boosting societal well-being: improving productivity or job creation in the food supply chain as a whole; improving the food security or nutrition status of the most vulnerable; and mitigating the negative environmental impacts of food loss and waste in terms of GHG emissions and pressure on land and water resources.

Public interventions towards food loss and waste reduction can be framed within a wider development agenda. Indeed, public policies that improve the business case for reduction among

private stakeholders (for example, improving road infrastructure or adjusting failures in credit markets) may have impacts that go beyond the mere reduction of food losses or waste and contribute to overall economic development. Meanwhile, policies that do not aim directly at reducing food loss and waste, but rather at broader development objectives, may have the corollary effect of improving the business case for reduction for private actors in the food supply chain. These issues are discussed in the last chapter of this report.

The extent to which food loss and waste reduction improves efficiency in the food supply chain on the one hand, and the benefits it brings to society overall in terms of food security and environmental sustainability on the other, may guide policymakers in determining how much public money to devote to this objective. However, the quantification and comparison of these effects may prove difficult in practice. For this reason, the next two chapters examine the extent to which reducing food loss and waste can help address issues related to food security and nutrition (Chapter 4) and environmental sustainability (Chapter 5). ■

MEXICO

A woman making tortillas in
her home in the village of
San Lorenzo.

©Alex Webb/Magnum Photos
for FAO



CHAPTER 4

FOOD LOSS AND WASTE AND THE IMPLICATIONS FOR FOOD SECURITY AND NUTRITION

Key messages

1 Reductions in food losses or waste may improve the food security and nutrition status of food-insecure groups, depending on where these groups are located and where the reductions are made. But positive food security impacts are not guaranteed, and in certain cases impacts may be negative for some groups, such as farmers.

2 A certain level of food loss and waste is needed as a buffer to ensure steady availability and access to food, especially as diets shift towards nutrient-rich, highly perishable foods.

3 The largest improvements in food security are likely to occur by reducing food losses in the early stages of the supply chain, especially on-farm, in countries with high levels of food insecurity.

4 The reduction of losses or waste further on in the supply chain may improve consumer access to food, but leave farmers worse off in terms of income and thus food security.

5 Reductions in food losses or waste in high-income countries have a limited impact in terms of overall food security. However, food recovery and redistribution programmes may increase access to food and improve diets of food-insecure individuals.

FOOD LOSS AND WASTE AND THE IMPLICATIONS FOR FOOD SECURITY AND NUTRITION

Ending hunger and malnutrition is enshrined in Targets 2.1 and 2.2 of SDG 2, to “end hunger, achieve food security and improved nutrition and promote sustainable agriculture”. However, world hunger has been on the rise in recent years.¹⁻³

It is often assumed that cutting food losses and waste will automatically help reduce world hunger and improve food security.⁴⁻⁷ It is also expected to improve the safety and nutritional quality of foods, especially in countries where many suffer from hunger and malnourishment.^{4, 8, 2}

However, the channels through which reductions in food losses or waste affect food security and nutrition are complex and context-dependent and need to be analysed carefully. The impact depends on how and where food losses or waste are reduced and the location of nutritionally vulnerable populations. It is not a given that food loss or waste reduction will improve food security and nutrition; in certain cases, its impact may even be negative. Moreover, a certain level of food loss and waste is needed as a buffer against price shocks and weather variability, to ensure that all people have access to adequate food at all times.

This chapter first discusses the relationship between food loss and waste and the different dimensions of food security. It goes on to examine to what extent loss or waste reductions can bring about improvements in food security and nutrition, based on context-specific cost-benefit analyses of various reduction measures. Finally it discusses the importance of the location of interventions for food security impacts and the relevance of countries' levels of income for determining appropriate intervention strategies. ■

FOOD LOSS AND WASTE AND ITS LINKS TO FOOD SECURITY AND NUTRITION

It is generally recognized that reductions in food losses or waste may improve food security and nutrition through the dimensions of food security: the availability of food, the economic and physical accessibility of food, food utilization, and the stability of food supplies and prices over time (see [Box 21](#) for definitions of these concepts).⁹ Some of these dimensions may overlap – for example, food cannot be accessed if it is not first available.

The relationship between food loss and waste and food security and nutrition is more complex than often assumed. [Figure 11](#) illustrates the potential interactions between decreases or increases in food loss and waste levels and these four dimensions, which may theoretically improve or worsen. The left side of the figure represents a food loss and waste reduction scenario (scenario A), while the right side depicts a situation in which losses or waste increase (scenario B). The arrows in the extreme right and left side of the figure separate the theoretically potential positive from the theoretically potential negative effects of a reduction (or increase) of food loss and waste on each of the dimensions of food security. Some of these interactions may be direct effects of the food loss and waste reduction (or increase), while others may be secondary effects, and the net effect becomes an empirical question – probably one that can only be tackled in an economy-wide framework where both supply and demand responses to price changes are properly represented, whereby net effects

BOX 21 FOOD SECURITY – KEY DEFINITIONS

Food security – A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, it is possible to identify four food security dimensions:

- ▶ **Availability** – This addresses whether or not food is actually or potentially physically present, including aspects of production, food reserves, markets and transportation and wild foods.
- ▶ **Access** – If food is actually or potentially present physically, the next question is whether or not households and individuals have sufficient access to that food.
- ▶ **Utilization** – If food is available and households have adequate access to it, the next issue is whether or not households are maximizing their

intake of adequate nutrition and energy. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, dietary diversity and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the *nutritional status* of individuals.

- ▶ **Stability** – If the dimensions of availability, access and utilization are sufficiently met, stability is the condition in which the whole system is stable, thus ensuring that households are food secure at all times. Stability issues can refer to short-term instability (which can lead to acute food insecurity) or medium- to long-term instability (which can lead to chronic food insecurity). Climatic, economic, social and political factors can all be sources of instability.

SOURCE: FAO *et al.*, 2018²

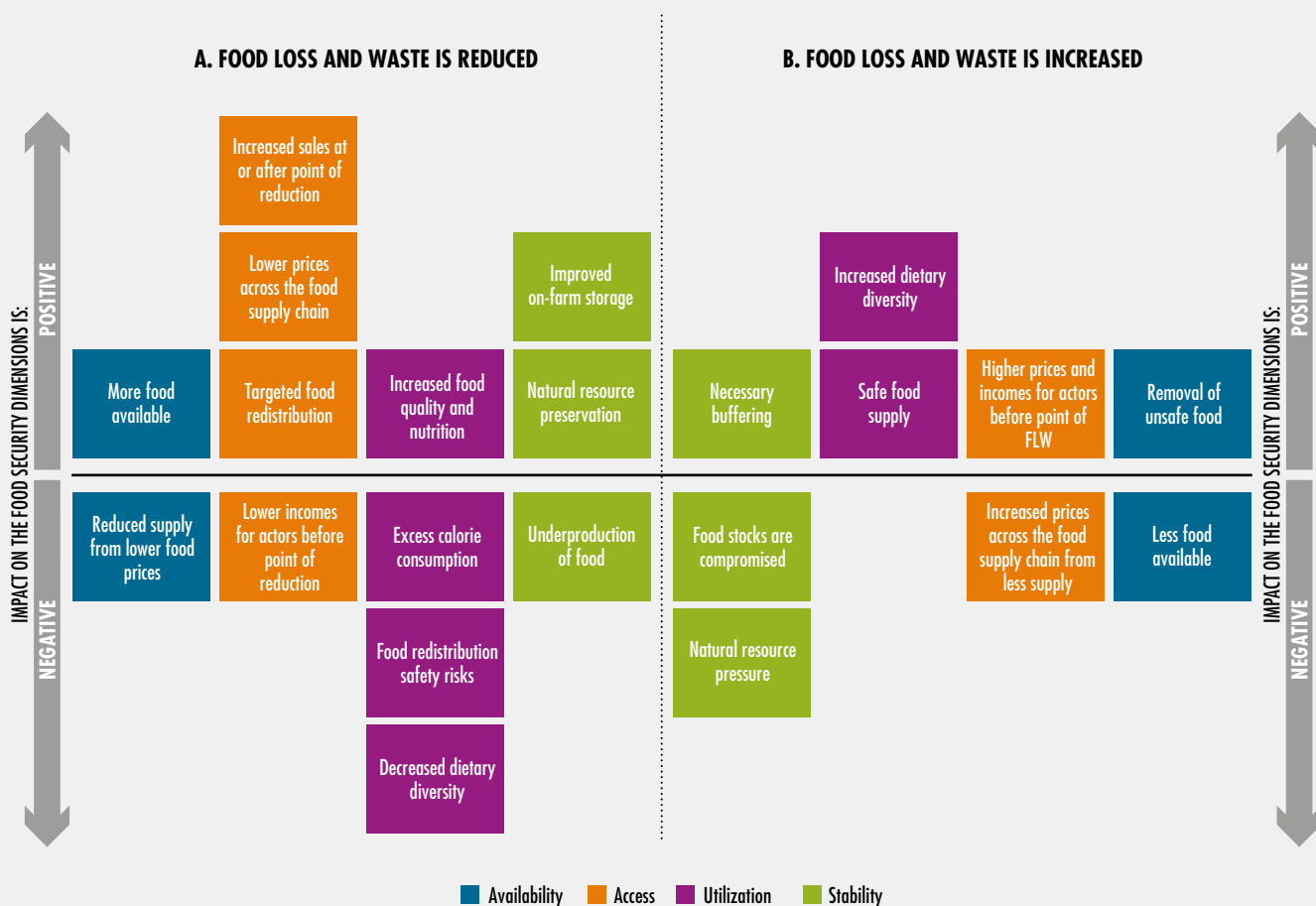
can be estimated. For instance, a reduction in food loss and waste may result in more food being immediately available, with an ensuing reduction of food prices. This, in turn, may then induce producers to reduce supplies – and, in an economy-wide setting, consumers may well react to this change. **Figure 11** shows potential effects, but the actual impacts experienced will depend on the context. In addition, since including all potential economy-wide effects of food loss and waste in a single figure would be impossible, **Figure 11** is only able to capture partial effects. How subsequent effects ultimately play out is an empirical question.

The following sections review the theoretical linkages between food loss and waste and these food security dimensions. Each section focuses on one dimension of food security, but the links to other dimensions are highlighted where appropriate.

The availability of food

It is often assumed that if less food is lost or wasted (scenario A of **Figure 11**), more food becomes available, which improves food security and nutrition (see the blue box in the top half). However, this improvement depends on where in the supply chain and in which geographical

FIGURE 11
THE POTENTIAL INTERACTIONS BETWEEN FOOD LOSS AND WASTE AND THE DIMENSIONS OF FOOD SECURITY



SOURCE: FAO

location food losses or waste are reduced and the main areas where food insecurity exists.

A reduction in the amount of food wasted by consumers in high-income countries, for example, does not necessarily mean there is more food available to poor households in distant, low-income countries. Subsistence or semi-subsistence farmers consume all or a considerable share of their own production. Thus, a reduction in on-farm losses is likely to improve their food security status, for example

by allowing them to store food for consumption during lean months. Meanwhile, a reduction in losses of food sold commercially improves the availability of food beyond farming households.⁹ For food-secure countries highly dependent on food imports, food loss and waste reduction is seen as a strategy for safeguarding their food supply.¹⁰

In Figure 11A, the blue box in the bottom quadrant shows that a food loss and waste reduction can also affect food availability negatively. Indeed, an

increase in food availability from a reduction in losses or waste may depress food prices. This can have a negative impact on supply and thus work against the initial improvement in food availability. The net effect is an empirical question that depends on a number of factors, including the price elasticities of supply and demand, the intensity of price transmission along the supply chain and the financial cost–benefit analysis of the reduction measure.

While food discarded for safety reasons lowers the amount of food available, it also improves the quality of the remaining food supply – thus preventing diseases which negatively impact on nutrition – and helps avoid detrimental trade effects. Therefore, in [Figure 11B](#), food safety discards are considered as positive impacts of food loss and waste, since these improve food security and nutrition. Unsafe foods should not be consumed and their detection requires proactive approaches to ensuring food safety. (For further discussion on food safety, see “The utilization of food” below.) Food safety discards could be partly avoided using a system approach promoting safety across the supply chain.

The accessibility of food

Improving the availability of food is only a first step towards improving food security and nutrition. Any additional food resulting from loss or waste reduction must also be physically and economically accessible to vulnerable populations.

The orange boxes above the horizontal axis in [Figure 11A](#) suggest that a reduction in food loss and waste will have a positive impact on the accessibility of food. However, as shown by the orange box in the bottom quadrant, negative effects may also arise. Whether the net effect of loss or waste reductions on food accessibility is positive or negative depends on the price effects of the reductions, which are in turn determined by the location of the reductions. How these price effects influence the incomes – and thus food security status – of households depends, in turn, on their income sources.

A fall in prices from loss reductions (second orange box above the horizontal axis of [Figure 11A](#)),

for example, improves consumers’ access to food, but may diminish the food security status of commercial farming households, who receive a lower price for their output (orange box below axis of [Figure 11A](#)). The food security status of semi-subsistence or subsistence farmers, on the other hand, is improved by a reduction in on-farm losses, which boosts the amount of food available to farming households. A reduction in the losses incurred by an individual acting in the supply chain boosts the amount of food that actor, as well as actors further downstream, can sell; this may increase their income and thus improve their food security status, as shown by the top orange box. If consumers waste less, they save money and can spend that money on more or better food.

Food recovery and redistribution efforts redirect food that would otherwise be lost or wasted to people in need, irrespective of their position in the supply chain.¹¹ Meanwhile, price discounts for food nearing its “best before” or “use by” date make that food more affordable, which may prevent it from being wasted.

The utilization of food

Avoiding qualitative food losses and waste (e.g. nutrient loss or food contamination) throughout the food supply chain ensures that more nutritious and healthy foods become available for consumers (see the purple box in the top half of [Figure 11A](#)).

However, safe and healthy diets necessitate a certain level of food loss and waste. Indeed, to ensure food safety, unsafe foods need to be discarded. A nutritious and diversified diet includes highly perishable food products such as fruits, vegetables and animal products, which are prone to spoilage. Both purple boxes in [Figure 11B](#) illustrate how the utilization of food may improve as food losses or waste increase.

As seen by the purple boxes in the bottom quadrant of [Figure 11A](#), reducing food losses or waste may also negatively impact on food security and nutrition. For example, redistributing food may improve food accessibility but may also lead to an increase in food safety risks if there is no guarantee of the safety of the redistributed food.

Reducing food losses or waste may narrow dietary diversity or lead to excess calorie consumption and intake of saturated fatty acids.^{12, 13}

The stability of food supplies

Food production and consumption levels vary over time, therefore food storage plays an important role in food stability. For farming households, improvements in on-farm storage, such as use of metal silos, can reduce loss and enable farmers to hold on to their harvest for a better sale price later in the season or for their own households' food consumption throughout the year (see the top green box in Figure 11A, under a reducing scenario). At all stages of the supply chain, a certain level of oversupply is needed as a buffer to ensure enough food is available even if production slackens or consumption expands.⁹ Maintaining such buffers inevitably causes a certain amount of food to be lost or wasted (shown by the top green box in Figure 11B). Reducing these losses or waste may jeopardize the stability of food supplies and prices, with negative impacts on food security (lower half of Figure 11A).⁹

On the other hand, food loss and waste may also have a negative impact on food stability. For example, losses caused by inadequate storage practices, on-farm or elsewhere (e.g. government buffer stocks of grains), may threaten the stability of food supplies (lower half of Figure 11B).

The production of food that is lost or wasted exerts undue pressure on natural resources (which may, in turn, pose a risk to the stability of food supplies, see lower half of Figure 11B). ■

FOOD LOSS AND WASTE AND THE IMPACT ON FOOD SECURITY AND NUTRITION

The characteristics of food production systems determine the availability and affordability of food, as well as food variety and dietary quality.¹⁴⁻¹⁸ Thus, food loss and waste on the one

hand and food security, nutrition and poverty on the other, may be closely connected, especially in low-income countries; however, the link has not been sufficiently researched.¹⁹⁻²¹ The absence of reliable and consistent data on the impacts of food loss and waste impedes comparisons between regions and countries.

Interest in food loss and waste reduction rose markedly during the 2007 and 2011 global food price spikes, which sparked concerns as to the ability of the growing world population to feed itself in the future.^{22, 23} Among the political commitments to reduce food loss and waste undertaken in the wake of these food price spikes is the African Union's Malabo Declaration (see Box 22).

It must be borne in mind that, for a number of reasons, food security and nutrition demand certain levels of food loss and waste. This is illustrated by the boxes above the horizontal axis in Figure 11B, when losses or waste are increased. First, good nutrition requires that unsafe food be removed from the food supply (blue box at the top of Figure 11B). Second, stability in food availability and prices requires an excess of available and accessible food to serve as a buffer, as shown by the green box in the upper half of Figure 11B. Little research has so far been done to explore which characteristics of a food system can ensure the stability dimension of food security in view of variable food production and dietary changes that are altering food consumption. Food loss and waste should be understood in connection with the need for appropriate buffering mechanisms that include some degree of excess in order to deal with the sometimes very high variability of production and consumption in time and in space,⁹ while maintaining an alternative plan to market surplus produce.

Third, as the availability of, and access to, diverse and nutrient-rich food increases, so too will food waste, as shown by the top purple box of Figure 11B. As some of the most nutrient-dense foods – those foods that are high in nutrients but relatively low in calories – have a short shelf life, the utilization dimension of food security and nutrition also requires careful review through a food loss and waste lens. Good nutrition requires a diverse diet, including fruits, vegetables and

BOX 22

THE MALABO DECLARATION AND THE PREVENTION OF POST-HARVEST LOSSES

Post-harvest losses erode incomes along the food supply chain and may exacerbate the vulnerability of poverty-ridden rural communities. In 2014 the African Union adopted the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods, which, under the commitment to end hunger in Africa, includes the target to halve current post-harvest losses by 2025. To this end, the African Union established the Post-Harvest Loss Management

Strategy, which combines all interventions across the entire food supply chain that aim to reduce post-harvest losses of food crops, including grains, fruits, vegetables and oilseeds, and animal and fishery products. The Post-Harvest Loss Management Strategy is expected to result in an increase in the amount and quality of food supplies and thus improve the availability, accessibility, utilization and stability dimensions of food security.²⁴

animal-sourced foods. A study in the United States of America found that higher-quality diets were associated with greater food waste.²⁵ However, reducing the quality loss of food products, which may happen, *inter alia*, as a result of vitamin or protein decay, can improve food utilization (nutrition) among consumers. Some processing methods, such as freezing, can prevent nutrient loss while preserving foods.^{26–28}

This section goes beyond theory to look at empirical evidence regarding the theoretical linkages between food loss and waste and food security and nutrition.

The impacts of food loss and waste reduction on food availability and access

Loss reduction along the supply chain

The reduction in food losses by suppliers, for example by adopting loss-reducing technologies, may lead to lower equilibrium prices for food and the supply and consumption of larger quantities of food. Such a scenario may bring welfare gains for both suppliers and consumers (see upper half of Figure 11A).¹⁹ Regulations or taxes that oblige suppliers to cut losses even where it is not financially rewarding to do so may have the opposite effect, i.e. a reduction in the quantity of food supplied and consumed and a higher

equilibrium price. A number of studies confirm that food loss or waste reduction can improve availability of and access to food; however, the effect is determined by the proximity of the reductions.

Drawing on FAO's 2011 food loss and waste estimates, one study looking at the market and trade impacts of food loss and waste reduction estimated that a 20 percent reduction in crop losses in developing countries over ten years would boost supplies and reduce prices, to the benefit of both developing and developed countries. For example, livestock and dairy producers in both groups of countries would see the costs of feed inputs go down. Some developing countries would increase their feed exports while others would import more at lower prices. Global rice production would increase by 5.5 million tonnes, with the international price decreasing by nearly 10 percent. Trade in rice between developing countries would increase.²⁹

A study based on an economy-wide modelling framework assesses the impact of reductions in food loss and waste in the European Union (EU) on producers and consumers in sub-Saharan Africa. The study finds that a reduction in agricultural losses in the EU means that producers demand fewer inputs to produce more

output. As a result, the supply of food in the EU increases, while food prices fall. The fall in food prices is partially transmitted to overseas markets, including sub-Saharan Africa, where consumers benefit from more affordable food imports. Meanwhile, the impact of reduced food losses in the EU on producers in sub-Saharan Africa is mixed. They benefit from the fall in the price of imported food to be used as an intermediate input, but are negatively affected by the competition from cheaper imports of final food products, forcing them to cut sales prices. Moreover, sub-Saharan Africa's exports to the EU have to compete there with lower-priced domestically produced food. As a result of the increased competition in both domestic and foreign markets, farmers in sub-Saharan Africa produce less than before.³⁰ A similar study using the same modelling framework found that the long-distance impact on food security in sub-Saharan Africa of a reduction in the amount of food wasted by retailers and households in the EU is positive, but relatively small.³¹

The reduction in food losses through better on-farm storage can improve the food security status of farming households. Smallholders are often compelled to sell all their grain soon after the harvest, because traditional storage facilities cannot guarantee protection against pests and pathogens. This may force them to buy grain for their own consumption later, at possibly higher prices. Case studies in Africa, Asia and Latin America have demonstrated that the use of metal silos prevents grain storage losses and enhances household food security.³² One study found that in Kenya, farmers who used metal silos to store maize had 1.8 months more in adequate food provisioning than non-adopters, which ensured the stability of their food consumption throughout the year. Metal silos allowed farmers to limit their immediate sales to those necessary to meet urgent cash needs and to hold on to the bulk of their harvest for up to five months after production.³³ As seen by the top green box in **Figure 11A**, when losses are reduced, improving storage can therefore help not only on-farm consumption, but also boost farmers' incomes.

Similar positive findings were found from the impact evaluation of the World Food

Programme's Zero Food Loss Initiative, a project aimed at reducing post-harvest crop loss in Uganda through the training of farmers in improved post-harvest handling techniques, and the introduction of subsidized, hermetic crop-storage technologies.³⁴ Farmers' incomes increased when employing hermetic crop bags, plastic silos, medium metal silos or large metal silos since it allowed them to sell the maize later in the season at a higher price, in comparison to traditional storage approaches or no storage at all. Food security likewise improved, reducing the external purchasing period for maize by 1.5 months and beans by nearly 1 month. Since adopting households consumed more of the food they harvested and stored, they also experienced greater financial flexibility, enabling them to consider other expenses and investments, such as children's education. Although, when surveyed, a sizeable portion of both technology adopters and non-adopters expressed willingness to pay more than the subsidized price but less than the normal retail price, the study estimated that strengthening the technology supply chains while phasing out subsidies over five years had a stronger effect on adoption than a ten-year subsidy. The success of the project in Uganda has spurred its expansion to over a dozen other African countries.

In many cases, bringing improved storage technologies to farmers requires incentivizing the private sector to start developing, marketing and selling on-farm storage solutions in locations accessible to smallholder farmers. In Kenya, an innovative strategy by the project AgResults launched a competition among operators with a cash sales bonus based on the volume of low-cost storage capacity sold. As a result, the improved storage sold corresponded to approximately 4.6 million 90-kg bags of maize safely stored from pests, thereby avoiding an estimated 12–20 percent loss. By improving business linkages, the competition pulled the hermetic storage devices into the last mile, enabling farmers to find a device at a nearby agrodealer.³⁵

Food recovery and redistribution

Food recovery and redistribution – also referred to as food rescue or donation – and gleaning are charitable acts that involve distributing food that would otherwise be lost or wasted to the food

insecure. Note that food may be recovered at any point along the food supply chain.

Neglected until only a decade ago by policymakers, recovery and redistribution programmes such as food banks, community shops, social supermarkets, pantry kitchens or school food and nutrition programmes are now playing an increasingly important role not only as food loss or waste solutions, but also as a means to promote the right to food.^{11,36} Indeed, as shown by the “targeted food redistribution” box in [Figure 11A](#), there is potential to influence food security and nutrition positively through food recovery and redistribution. However, this can only ever serve as a safety net and cannot be a solution to eliminate either food insecurity or food loss and waste. As food recovery and redistribution becomes more important, so does the need to appraise its impacts critically.¹¹

Food redistribution does not necessarily mean food is handed out for free. Social supermarkets, for example, sell food that is rejected for sale in the mainstream market (e.g. blemished fruits and vegetables or excess stock) at discounted prices.¹¹ Note that food recovery and redistribution programmes should be formulated so as to deliver food in ways that are not considered demeaning by recipients.¹¹ Redistributed food must also be culturally acceptable and adapted to local tastes.

The potential for food recovery and redistribution to make an impact is illustrated by efforts in the United Kingdom of Great Britain and Northern Ireland under the Courtauld Commitment 2020 to reduce food waste. From 2015, when it was adopted, until 2017, an additional 35 million meals were redistributed annually. In 2017, 102 million meals were redistributed, at a total value of almost GBP 130 million.³⁷

A study into food redistribution in Denver, New York and Nashville in the United States of America found a realistic potential to redistribute an additional 24 million meals annually. This would enable the three cities to meet an additional 8–18 percent of their respective meal gaps. The study found that grocery outlets presented the largest untapped potential for food recovery in terms of the total

amount of food to be recovered. Institutional catering offers the advantage of concentrating significant volumes of food in a relatively small number of locations; it was therefore a priority target in the study.³⁸

The Daily Table, a not-for-profit grocery store in a low-income neighbourhood in Boston, in the United States of America, sells healthy meals priced to compete with fast food alternatives by recovering food discarded by retailers, growers and distributors.³⁹ The prices make it possible to purchase three balanced, wholesome meals and one snack a day on a Supplemental Nutrition Assistance Program budget, the government’s food assistance allowance for low- and no-income people.⁴⁰ The Daily Table was founded on the premise that making people pay for their food, as opposed to giving it to them for free, avoids them feeling any shame.⁴¹

Food recovery and redistribution practices are expanding rapidly around the world. In countries where social safety systems are underfunded, overburdened or non-existent, food recovery and redistribution programmes have proved an effective form of food assistance, as well as a key element of progressive social policy. In Brazil, for example, a national network of food banks, Mesa Brasil SESC, served more than 1.4 million Brazilians through public–private partnerships in more than 500 municipalities in 2017.⁴² The Egyptian Food Bank fed an average 250 000 people monthly in 2017. The Bank has helped launch 33 food banks in the Near East, Africa and Southern Asia since 2011. In 2017 it extended its reach to Latin America, where it participated in launching 61 food banks.⁴³ In North Macedonia, a web platform launched by NGO Ajde Makedonija connects businesses with surplus food for donating to civil society organizations that redistribute the food to food-insecure people.⁴⁴ An Asian example of successful food redistribution is the No Food Waste initiative in India, which redistributes large quantities of leftovers from social events, hotels and restaurants. Overall, however, food recovery and redistribution programmes in Asia and the Pacific are rare and mainly concentrated in the high-income countries of the region.¹¹

Food loss and waste reduction and stability in the supply and prices of food

Food production and consumption levels vary over time. Therefore, a certain level of oversupply or buffer is needed at all stages of the supply chain to ensure availability and access to food in case production drops or consumption expands.⁹ Maintaining such buffers necessarily entails a certain level of food loss and waste. On the other hand, loss and waste reduction measures, such as better storage or preservation methods, may help counter the seasonality of agricultural products and thus promote the stability of food supplies which will help improve access.²³ The linkages between food loss and waste and the stability of food are depicted in **Figure 11**.

Any studies into food loss and waste must take due account of the need for buffers to ensure food supply stability against a background of variations in production and consumption in time and space.⁹ Options to market any excess supplies that go with such buffers need to be explored.

High levels of waste can jeopardize the continuity of food assistance programmes and the food security of those served. The Breakfast in the Classroom programme in the United States of America, for example, has high levels of milk waste. It was estimated that the value of the milk wasted in one urban school district was 16 percent of annual food expenditure under the programme for that district, excluding the costs of disposing of the wasted milk in landfill.⁴⁵

The impact of food loss and waste reduction on nutrition

Nutrient loss due to quantitative and qualitative food loss and waste may represent a missed opportunity to reduce malnutrition and micronutrient deficiencies.¹²

A recent study based on FAO's 2011 food loss and waste estimates found that while the supply of all digestible protein, fat, calories, amino acids and essential vitamins and minerals exceeded average requirements, the large amounts of food lost throughout the food supply chain compound dietary inequalities within and between countries. The results of the study further indicate that over

60 percent of total micronutrients, with the exception of vitamin B12, are lost as a result of the loss and waste of highly perishable foods, including fruits, vegetables and animal-based products. The study concludes that strategies focusing on improved storage and distribution management are likely to improve the availability of micronutrients more than that of macronutrients.⁴⁶

Another study, also based on FAO's 2011 food loss and waste estimates, finds that reducing food losses and waste by half would considerably boost nutrient supplies in the food system in 2030.¹³ In high- and upper-middle-income countries, the supply of dietary iron would increase above recommended levels, while folate deficiencies would decrease fourfold but remain below recommended values. In lower-middle-income countries, the supply of folate would exceed recommended intake values and riboflavin (B2) deficiencies would be halved. In low-income countries, the supply of calories would allow all consumers to increase their intake to levels above minimum recommended values, assuming universal and equal access to those calories. The supply of vitamin A, riboflavin, folate, calcium and polyunsaturated fats, crucial for the prevention of non-communicable diseases, would all increase by one-third to one-half of current, inadequate levels. By boosting the supply of nutrients, halving food loss and waste would also have an effect on risk factors for chronic, non-communicable diseases among adults, such as coronary heart disease and type 2 diabetes, which are becoming more prevalent in low- and middle-income countries. The study estimates that two million deaths could be avoided by halving food loss and waste, mainly due to increased consumption of fruits and vegetables.

The study estimates unintended consequences, too. Deaths due to overweight and obesity are set to increase by over half a million in 2020, due to excess consumption of calories and saturated fatty acids. Meanwhile, rises in food losses and waste cause supply gaps for certain nutrients. The supply of folate and riboflavin would fall short of demand in lower-middle-income countries, as would that of vitamin A, riboflavin, folate, calcium and polyunsaturated fatty acids in low-income countries. Importantly, even

the supply of calories would be insufficient in low-income countries. The underlying assumption with these results is that changes in nutrient availability would result in increased accessibility, therefore the study is only indicative of possible change. However, these results are valuable as they demonstrate that food loss and waste reduction should go hand in hand with health-sensitive interventions aimed at optimizing the impact of loss and waste reductions on nutrition.

FAO recently piloted a method to estimate the percentage of children under five in Cameroon, India and Kenya whose micronutrient requirements of vitamin A, iron, zinc and vitamin C could theoretically be satisfied through reductions in food losses (see [Box 23](#)). The study shows that large amounts of nutrients are lost due to preventable post-harvest losses. It demonstrates that reducing post-harvest losses of selected crops could increase the availability of micronutrients, which could in turn improve nutrition.⁴⁷ The study is the first to estimate the connection between nutrient loss in the food supply chain and micronutrient deficiencies in children. However, its results should be interpreted with caution. The study assumes that food loss decreases the intake of food and its nutrients by nutrient-deficient people and that micronutrient-deficient children would have access to the recovered nutrients. In reality, the lead cause of micronutrient deficiencies in children is not a lack of access to food, but rather infections, which reduce appetite and hamper the utilization of nutrients.^{48–50}

Fish and fish products are a source of valuable nutrients and micronutrients and are thus of fundamental importance to healthy, diversified diets. Fish can be a relatively cheap, locally available means to diversify the diet of low-income groups. However, fish spoils easily and post-harvest handling, processing, packaging, storage and transportation require particular care to maintain quality and avoid losses and waste. Alongside the rise in consumption of fish products in recent decades, there is a growing interest in food quality and safety, with increasingly stringent hygiene standards at national and international levels.⁵²

Up to 55 percent of (typically inedible) fish inputs are lost during processing. However, even fish parts generally considered inedible may be used as inputs for processed fish-based food products. This would boost the incomes of fish product suppliers and provide more nutritious food for consumers.⁵³

Mechanical fish separation involves the use of non-marketable fish parts to produce processed food products (e.g. fish burgers). An Italian study found that the mechanical separation of non-marketable fish parts and their use for the production of fish-based products like fish burgers creates new opportunities for the fish industry and increases the availability of highly nutritious foods for consumers.⁵³

Food safety and its implications for food security and nutrition

Food safety, which can be associated with food loss and waste or interventions to reduce it, is of crucial importance to food security and nutrition. Food-borne illnesses caused by the consumption of contaminated foods, for example, hamper nutritional intake. Food that is not safe must be removed from the food system, resulting in losses; but, on the other hand, qualitative food loss reduction may increase food safety. These effects are illustrated by the purple boxes in both scenarios of [Figure 11](#).

Depending on the context, food safety and food loss and waste may be causally linked, negatively or positively. First, the disposal of unsafe food can be considered as food loss. Second, many of the practices that prevent physical food loss and observable losses in quality also improve food safety. It is often easier to motivate food actors to limit observable losses, since they have financial implications; improvements in food safety then become a welcome by-product of loss reduction. Third, producers and suppliers may apply chemicals to food to protect it against pests or preserve it. While this may prevent food from being lost or wasted, it can also threaten food safety and undermine consumer confidence in the safety of their food. For this reason, the “safe food supply” box in [Figure 11B](#) is considered as a positive effect from increased levels of food loss and waste.



BOX 23
THE IMPACTS OF FOOD LOSS ON MICRONUTRIENT DEFICIENCIES IN CHILDREN UNDER FIVE

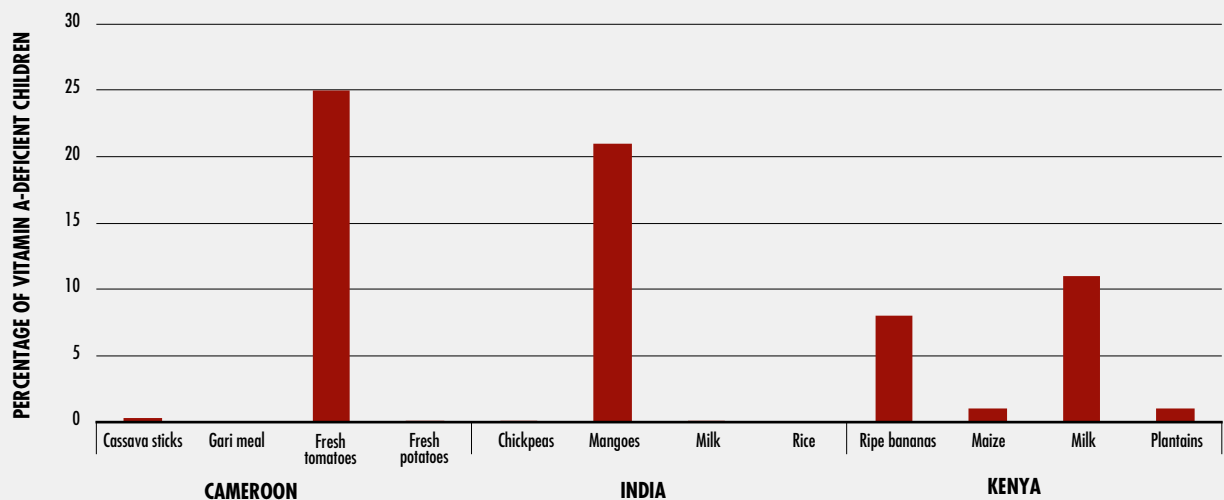
A pilot study by FAO in Cameroon, India and Kenya established a link between the amount of losses for a number of food products (selected because of their importance in diets, and the availability of up-to-date nutrient data) and the loss of nutrients. Vitamin A deficiency is a major health and nutrition concern in developing countries. It is the leading cause of preventable blindness in children and increases the risk of disease and death from severe infections.⁵¹ FAO estimates that the requirements of nearly a quarter of vitamin A-deficient children in the three countries in the study could theoretically be satisfied through food loss reduction. The figure in this box shows how this potential varies from one food product to another.

Due to a lack of country-specific data on zinc, iron and vitamin C deficiencies for children under five, the study used the percentages of all children under five in each country whose nutritional needs could theoretically be satisfied by food loss reduction, regardless of their nutritional status. The results of the

study vary considerably between countries and nutrients. In Kenya, food loss reductions are assumed to satisfy the iron and vitamin C requirements of 24 and 33 percent, respectively, of all children under five. In Cameroon, loss reductions could satisfy the vitamin C needs of 83 percent of all children under five. In India, food loss reductions were unable to satisfy nearly any of the iron or zinc requirements; however, 23 percent of children in the country would receive their requirements for vitamin C through loss reduction.

Note that the validity of the study results is determined by the multitude of assumptions used, as well as by the gaps in country-specific data on nutrient deficiencies and food composition. In addition, the methodology to estimate post-harvest losses is inconsistent across countries and food products. The study also fails to factor in the logistical and other costs of addressing nutrient deficiencies through food loss reduction. In view of these shortcomings, the study's case for addressing nutrient deficiencies in children by reducing food losses is weak.

PERCENTAGE OF VITAMIN A-DEFICIENT CHILDREN UNDER FIVE WHOSE DEFICIENCY COULD THEORETICALLY BE SATISFIED THROUGH FOOD LOSS REDUCTIONS, BY COUNTRY AND FOOD PRODUCT



SOURCE: Lee *et al.*, 2019⁴⁷

BOX 24 GENDER RELATIONS INFLUENCE FOOD SAFETY AND FOOD LOSSES – THE CASE OF RURAL ETHIOPIA

Where women play a primary role in agriculture, inclusive interventions towards loss reduction can improve food availability and accessibility. Rural women often have less access to and control over resources than men, which may result in the loss of food. In addition, the work assigned to women is often arduous, time-consuming and repetitive, much of it around the home in conjunction with household and caring tasks. This double or triple role carries a heavy time and energy burden and can significantly contribute to food loss.⁶⁵

In rural Ethiopia, women are often responsible for preventing grain loss during storage, but they have less access to and control over agricultural assets than men. One study finds that women's disempowerment forces them to resort to less effective methods to prevent losses. Some of these methods may threaten food

safety. Treating grain with chemicals, for example, can pose a threat to human health and affect the nutritional value of the grain. Women report applying chemicals above the recommended levels to avoid losses and conflict with men. Poor storage conditions increase the likelihood of contamination, which further promotes the use of chemicals – to which women are especially exposed. To overcome food gaps when cash is short and production yields are poor, women reported consuming grains of which up to 50 percent were damaged.⁶⁶

Gender-responsive interventions to improve women's standing and decision-making power in the consumption and sale of household production may help reduce food losses, and thus strengthen food security, not least by improving food safety and dietary diversity (see also Chapter 6).^{67–70}

» The detection of food safety hazards may result in the loss of food products. The nature and extent of contamination, together with the effectiveness of food safety regulations, determine the scale of the loss. For example, the Kenyan Government destroyed nearly 14 000 tonnes of maize in 2014 due to contamination with aflatoxins, a type of mycotoxin produced by a fungal infestation of crops.⁵⁴ Mycotoxins are toxic and can cause extensive harm to human and animal health.^{55–57} Food safety concerns that are unverified by experts may result in precautionary destruction which in some cases can be mitigated with expert consultation. For instance, fears that mangoes had been treated with formalin led the Government of Bangladesh to destroy hundreds of tonnes of the fruits, while safety experts later concluded they posed no risk to human health.⁵⁸ Similarly, stringent food safety regulations produce extensive losses.

In other cases, especially where food safety standards or their enforcement are weak, the detection of food safety hazards may lower the value of food products. Suppliers may divert

contaminated food to poorer buyers, for example in the informal sector. This may entail financial losses, without eliminating the food safety risk. Unsafe food is often diverted to lower-income groups that are physically and economically vulnerable to disease.⁵⁹ National estimates indicate that dietary exposure to mycotoxins in developing countries is much greater than in developed countries.⁸ Mean dietary exposures in sub-Saharan African countries, for example, are 100 times greater than those in developed countries.⁶⁰ A study of rural women in Kenya found that high levels of mycotoxin exposure were strongly associated with poverty – in particular, a lack of disposable income for household expenditure – as well as with food insecurity and severe hunger.⁶¹ A study in Ethiopia found that women's lack of control over agricultural assets contributes to the consumption of grain contaminated by fungi or pests. **Box 24** discusses the Ethiopia case study in the broader context of women's empowerment and its connection to food loss and food security.

Food safety hazards are often invisible to the eye and difficult to measure without specialized equipment. Suppliers may therefore have little incentive to control food safety risks. If enforcement of food safety regulations is weak, unsafe food may enter the market. Suppliers are typically more motivated to address quantitative losses or observable quality deterioration that affect marketable volumes. Measures aimed at limiting such losses may also promote food safety. For example, the use of hermetic bags to store grain drastically reduces observable, quantitative losses, but also prevents contamination with fungal toxins.^{62, 63} Refrigeration inhibits the growth of most bacteria that cause food to spoil, as well as those that have adverse health effects.

In contexts where regulation is lacking or unenforced, food loss reduction measures can compromise food safety. For example, pesticides may prevent on-farm losses, but can be harmful to human health; chemical preservatives may prevent food spoilage, but can also be hazardous. An example is the treatment of fish, meat and milk with formaldehyde for preservation. As formaldehyde also occurs naturally in these foods (its presence increases over time as a by-product of decomposition), adulteration with formaldehyde is difficult to detect.⁶⁴ The continued monitoring of food for the presence of harmful preservatives is important to ensure consumer confidence in its safety.

The recent growth in food recovery and redistribution initiatives may give rise to food safety concerns. While some countries (such as Canada, New Zealand, the United States of America and a number of European countries) have formulated regulations and guidelines related to food recovery and redistribution, others do not impose any rules or controls on these often spontaneous and uncategorized practices. This lack of regulation and oversight poses food safety risks.¹¹

The above findings demonstrate the need for inclusive food safety policies that ensure no one, especially the most vulnerable, is forced to consume contaminated foods due to lack of access to safe alternatives. Discarding unsafe food will always be preferable to consuming it. What is really required is a reduction in the

occurrence of food safety hazards in foods, in particular those with the highest risks to human health. In addition, unsafe food discards should be removed from the food supply chain in a way that ensures they do not end up being consumed. ■

FOOD LOSS AND WASTE REDUCTION AND THE IMPORTANCE OF LOCATION

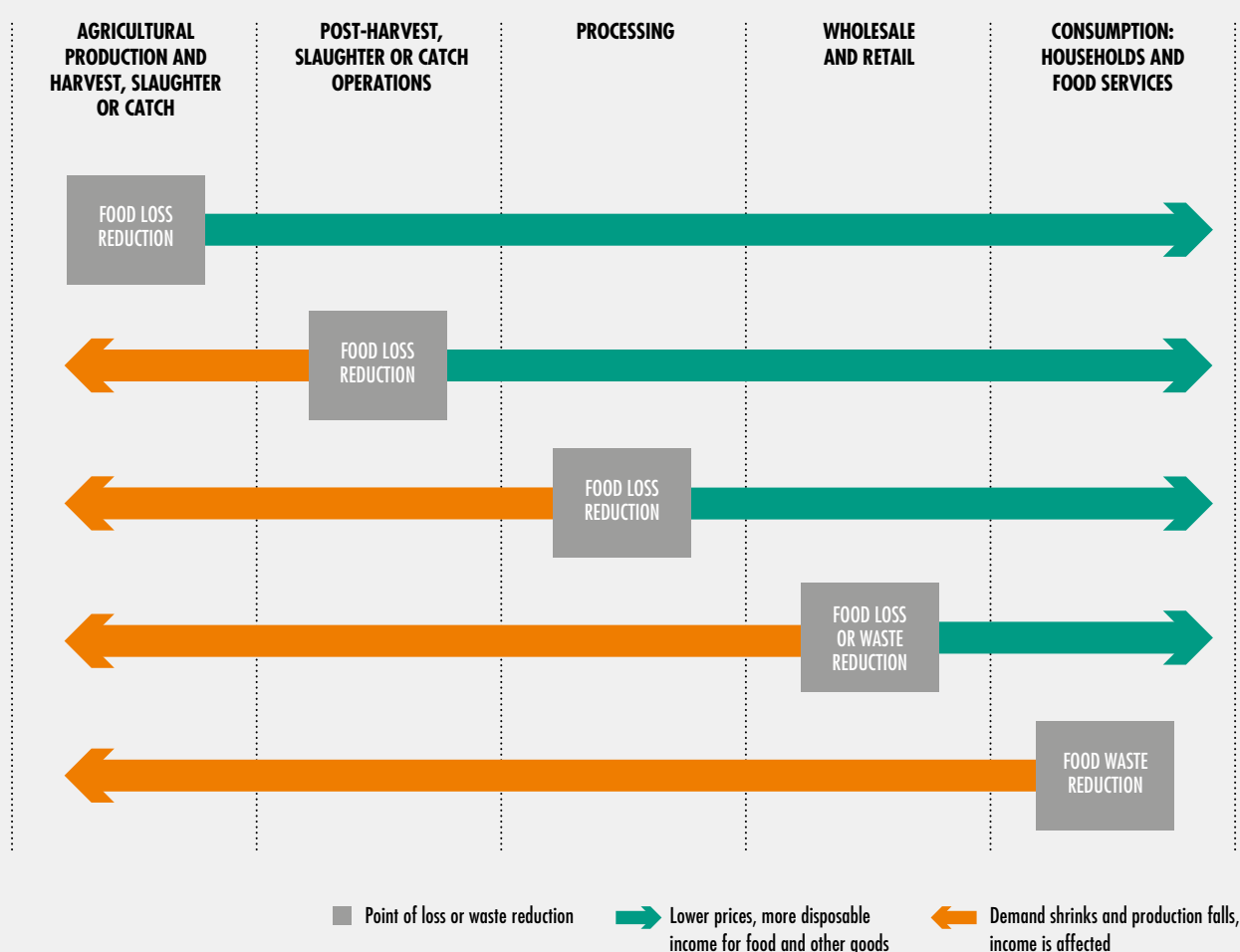
As seen above, food loss and waste reductions may affect food security and nutrition in various ways, depending on the location of the reductions and the food-insecure groups, both geographically and along the supply chain.

The impacts operate through different channels. Food loss and waste negatively affect the quantity and quality of food supplies; and they also affect prices and thus the equilibrium of the food system. These in turn affect the income of actors along the supply chain and ultimately food security beyond the affected supply chain (primarily through price changes).

A reduction in food losses or waste at a given stage in the supply chain increases the amount of food supplied to subsequent stages. This depresses prices paid by the stakeholders in these stages, boosting their incomes (shown by the “increased sales at or after point of reduction” box in [Figure 11A](#)). The impact on the income of those who achieve the reduction, however, depends on how much their sales volume increases and how much prices fall. Actors operating at earlier stages in the supply chain may be negatively affected if a reduction in losses or waste by their buyers means the demand for their output falls and their sale price goes down. As a result, incomes, and therefore the food security status of these upstream actors, decline (see orange box below the axis of [Figure 11A](#)).

Note that lower prices may entice consumers to trade up their food purchases to more expensive, higher-quality food; this works to offset the

FIGURE 12
POTENTIAL PRICE AND INCOME EFFECTS OF FOOD LOSS AND WASTE REDUCTIONS AT VARIOUS POINTS
IN THE FOOD SUPPLY CHAIN



SOURCE: FAO

negative impact on suppliers' incomes of a reduction in consumer waste. The negative impact of a reduction in food loss and waste on the income of downstream suppliers may also be counterbalanced by population and income growth.

Figure 12 illustrates the potential price and income effects of a reduction in food losses or waste at various stages of the food supply chain. The turquoise arrows show how an increase in

the food supply resulting from reduced loss or waste depresses food prices further down the food supply chain and thus improves access to food at these stages.

A reduction in on-farm losses may have strong positive food security impacts. This is particularly true for smallholders in low-income countries where the availability of food for subsistence farmers improves. Farmers who market part of their output have larger volumes to sell and thus »

BOX 25

THE IMPACTS OF A REDUCTION IN FOOD LOSSES AT THE PRIMARY PRODUCTION AND FOOD PROCESSING STAGES ON FOOD SECURITY AND NUTRITION

Wageningen Economic Research carried out a simulation exercise, commissioned by FAO, of the impact of a 25 percent reduction – in terms of economic value – in global food losses in primary production and food processing, based on FAO's most recent food loss estimates. The simulation was carried out in MAGNET, a multisectoral, multiregional computable general equilibrium model of the world economy that is widely used to simulate the effects of agricultural, trade, land and biofuel policies on the global economy.⁷² It aimed to understand how loss reductions impact on food security and nutrition through prices.^{i,ii} The 25 percent reduction in losses can be represented as changes in productivity that increase global food production by 4.3 percent, of which 2 percent is at the primary production stage and 2.3 percent at the processing stage. The table in this box indicates the impact of the loss reduction on economic and food security and nutrition indicators globally and in sub-Saharan Africa and Central and Southern Asia, where food insecurity is prevalent.

The results of the model show that a worldwide reduction in food losses brings about an improvement in global economic and food security and nutrition indicators. World Gross Domestic Product (GDP), as an indicator capturing the overall response of the global economy to the effects of the loss reduction on efficiency, increases (moderately) following the reduction. Both the availability (measured as total primary food production) and the access (measured as food purchases by private consumers) to food improve after the loss reduction as a result of its effects on prices and incomes. The model does not capture actual intake; however, it shows that the nutrient content of the three micronutrients for which global intake of food is inadequate increases, indicating an improvement in food utilization.⁷³

The improvements in global indicators, ranging between 0.1 and 0.6 percent, are not large; however, two factors should be taken into account when interpreting these changes. First, the demand for food is all in all not very responsive to price changes. Thus, while the model predicts that the loss reduction and the resulting boost in the amount of food available at retail

level will lead to a global fall in food prices of 4 percent, food purchases do not increase significantly (+ 0.53 percent). Second, the changes in indicators vary widely across regions. GDP and total primary production in regions with generally lower levels of per capita income are found to be generally more responsive to loss reduction, as the agriculture and food sectors in these countries typically account for a larger share of the economy.

These results help identify the best entry points for loss reduction aimed at improving food security and nutrition. The table distinguishes between the contributions to changes in GDP and three of the food security dimensions as a result of interventions in the primary production stage on the one hand, and in the processing stage on the other.

Interventions that reduce losses have a larger impact on food security and nutrition indicators in the primary production stage than those in the processing stage. The difference is particularly stark for availability: in both sub-Saharan Africa and Central and Southern Asia, primary production decreases as a result of a fall in prices brought about by loss reduction at the processing stage. These loss reductions can negatively affect the food security of vulnerable farming households, as they are output-augmenting at production but input-saving at the processing stage.

The impact of loss reduction on access and utilization is positive at both stages of the supply chain. In sub-Saharan Africa, loss reduction at the primary production stage has an impact that is around 20 times stronger than it is at the processing stage and 10 times stronger than at the processing stage in Central and Southern Asia. These results confirm that interventions towards loss reduction focusing on the early stages of the supply chain are more effective in achieving better food security and nutrition outcomes.

The results of the modelling exercise demonstrate that the impact of loss reductions on food security and nutrition is much stronger domestically than abroad. They show that loss reduction improves food access and utilization both domestically and abroad, but reductions abroad have a negative impact on the

BOX 25
(CONTINUED)

availability of food in both sub-Saharan Africa and Central and Southern Asia. This result is explained by the fact that imports replace domestically produced food. Indeed, the loss reduction abroad results in a fall in the price of imports, discouraging demand for domestic food and favouring cheaper imports. The

indicators for food access and utilization are based on a combination of domestically produced food and imported food while the fall in prices results in an improvement in these two indicators.

SOURCE: Kuiper and Cui, 2019⁷²

FOOD SECURITY AND NUTRITION IMPACTS OF A 25 PERCENT REDUCTION IN FOOD LOSSES AT THE PRIMARY PRODUCTION AND PROCESSING STAGES OF THE SUPPLY CHAIN, PERCENTAGE CHANGE

	Economic impact	Food security and nutrition						
		Availability	Access	Utilization				
				Macronutrients		Micronutrients		
				Calories	Protein	Vitamin A	Calcium	Zinc
Global	0.12	0.13	0.53	0.47	0.53	0.59	0.60	0.54
Sub-Saharan Africa (Total)	0.57	1.02	0.67	0.75	0.70	0.62	0.96	0.74
Contribution of primary production	0.55	1.09	0.64	0.72	0.66	0.60	0.92	0.71
Contribution of processing	0.02	-0.08	0.03	0.03	0.04	0.03	0.04	0.03
Contribution of domestic reduction	0.57	1.85	0.56	0.63	0.59	0.53	0.82	0.62
Contribution of foreign reduction	0.00	-0.84	0.10	0.13	0.11	0.10	0.14	0.12
Central and Southern Asia (Total)	0.22	0.07	0.32	0.19	0.24	0.36	0.27	0.26
Contribution of primary production	0.20	0.15	0.29	0.17	0.22	0.33	0.24	0.24
Contribution of processing	0.02	-0.09	0.03	0.02	0.02	0.03	0.02	0.02
Contribution of domestic reduction	0.22	0.62	0.25	0.16	0.20	0.24	0.20	0.20
Contribution of foreign reduction	0.00	-0.56	0.07	0.03	0.04	0.12	0.07	0.06

ⁱ Details of the modelling framework, scenario set-up and simulation results for all regions can be found in the background paper, Kuiper and Cui, 2019.⁷²

ⁱⁱ FAO's Statistics Division provided food loss estimates by food group, country group and supply chain stage. In the simulation exercise, food loss reductions vary across food products, regions and supply chain stages. However, due to the difference between FAO's food loss estimation methodology and the structure of MAGNET, the supply chain stages included in the simulation exercise are limited to the primary production and processing stages; other supply chain stages, such as storage, transportation, wholesale and retail, are not covered.

- » their incomes and food security may increase, provided the price drop resulting from the output boost does not offset this effect.

A reduction in losses or waste by suppliers beyond the primary production stage boosts supplies and lowers prices further along the supply chain. However, farmers may see the demand for their products decrease, with negative implications for their incomes and thus food security, shown by the orange arrows in [Figure 12](#).

A reduction in the amount of food wasted by consumers improves food availability and access for consumers, but the resulting reduction in consumer demand may leave farmers and other actors in the supply chain worse off.

Consumers increase their disposable income by cutting back waste, which may lead them to change their diet to include a wider range of nutritious, perishable products, e.g. meat, fish, fruits and vegetables.⁷¹ The following result may well be an increase in the amount of food wasted, in particular food with a higher environmental footprint.³⁰

How food loss and waste reductions impact on the incomes, and thus food security status, of stakeholders in the food supply chain depends on how price changes ripple through it. Geographical proximity largely determines the strength of this price transmission. The likelihood that a reduction in losses or waste will improve the food security status of groups located far away from the point of reduction is small. A reduction in food wasted by consumers in high-income countries, for example, does not necessarily mean the recovered food becomes available to the food insecure in a low-income country, nor do they automatically benefit from the price drop resulting from waste reduction.

Drawing on FAO's new estimate of food losses (from the Food Loss Index described in Chapter 1), [Box 25](#) presents the results of an economy-wide modelling exercise to assess transmission of the impacts of a 25 percent drop in global food losses or waste on food security and nutrition across the primary production and food processing stages of the supply chain and across regions. It shows that a worldwide reduction in

food losses brings about a modest improvement in global economic and food security indicators. However, the results demonstrate that while a fall in prices resulting from loss or waste reduction in developed countries may improve food access for food-buying households in developing countries, it may also depress incomes, and thus undermine the food security and nutrition status of farming households in these countries. ■

FOOD LOSS AND WASTE REDUCTION AND LEVELS OF FOOD INSECURITY

The role of food loss and waste reduction in lowering food insecurity also depends on the degree of food insecurity prevalent in different countries. A global measurement of the severity of food insecurity is available through the Food Insecurity Experience Scale (FIES),^p which measures limits in access to food, at the level of households or individuals, due to lack of resources. Respondents are asked eight direct yes/no questions about their experiences in accessing food over the previous 12 months.³ Based on the responses, levels of food insecurity are assessed according to the following scale:

- severely food insecure: no food for a day or more;
- moderately food insecure: compromising on food quality and variety or reducing food quantity and skipping meals;
- mildly food insecure or food secure: potential uncertainty about the ability to obtain food.

The FIES provides useful insights into the degree of urgency of ensuring food access, including food quality considerations. Where severe food insecurity is high – as in low-income and lower-middle-income countries, as shown in [Table 1](#) – the scope for food loss and waste reduction to contribute to reducing hunger through increased availability and access to food is potentially large. Interventions preventing avoidable food loss can ameliorate food shortages, particularly at local level in smallholder production as these areas

p For details on how the FIES is calculated, see FAO *et al.*, 2019.³

TABLE 1
PREVALENCE OF FOOD INSECURITY (PERCENTAGE OF TOTAL POPULATION) BY FIES CATEGORY AND INCOME GROUP, 2016

	Severely food insecure	Moderately food insecure	Mildly food insecure or food secure
Low income	27	34	39
Lower-middle income	10	20	69
Upper-middle income	4	12	84
High income	1	6	92

SOURCE: FAO *et al.*, 2019³

are not well connected to markets and therefore trade is minimal.⁷⁴ This could increase farmers' incomes and improve food access. If reductions in losses are large enough to affect prices, the urban food insecure may also stand to benefit. Overall, a strategy aiming to reduce food loss and waste is likely to be more effective in improving food security for the populations in these countries than in high-income countries, particularly by focusing on reducing losses at the farm level and early steps in the supply chain.

As levels of severe food insecurity recede – in upper-middle-income and, particularly, high-income countries – the importance of food loss and waste reduction in terms of improvements in food security declines. Also the nature of the required strategies changes as more targeted approaches are needed to reach the food insecure, e.g. through the redistribution of food in urban areas, which often experience rising levels of waste. Especially in high-income countries, problems of food access touch on a much smaller share of the population, even though numbers of moderately food insecure remain relatively significant. Large-scale campaigns to reduce food waste – the most pressing problem related to food loss and waste in high-income countries – are unlikely to benefit the remaining numbers of food-insecure people. Targeted loss or waste reduction interventions, such as redistributing food, especially well-balanced meals, to the food insecure may do more to improve access to quality and nutritious food by the severely and moderately food insecure. However, eliminating lingering food insecurity will also require a broad set of social policies addressing its underlying causes.

It has to be borne in mind that poverty and inequalities are drivers of food insecurity.³ Hence, interventions aimed directly at reducing poverty and inequalities may be more effective at improving food security than food loss or waste reduction. The latter can make a contribution but cannot be considered the solution to the food insecurity problem. Also note that food waste levels on the one hand, and food insecurity indicators on the other, generally do not move in the same direction. A rise in incomes often results in an increase in food waste as households buy more food, though the share of food in the overall household budget falls and diets shift towards more perishable foods: meat, fruits and vegetables. An increase in food waste may thus be a symptom of greater food security. However, an increase in food losses indicates that the availability of food is negatively impacted by structural problems, such as insufficient agricultural infrastructure.⁷⁵ ■

THE RELATIVE (COST-)EFFECTIVENESS OF FOOD LOSS AND WASTE REDUCTION IN IMPROVING FOOD SECURITY AND NUTRITION

So far, this chapter has examined whether food security and nutrition can be improved by reducing food loss and waste at different stages in the supply chain. It has argued that positive effects are not a given and that the impact depends on location, both geographically and along the supply chain, of the loss or waste reduction and of the food insecure. The discussion has shown that loss or waste reductions are most likely to improve food security and nutrition if they occur near the food insecure.

This chapter has examined evidence as to the effectiveness of loss and waste interventions at different stages in the food supply chain in terms of food security and nutrition. The limited data available suggest that certain interventions may not bring about a significant improvement. Food waste reductions in high-income countries, in particular, are unlikely to have a more than negligible impact on food security and nutrition in low-income countries. The reduction of on-farm losses in these countries themselves is more likely to have a significantly positive impact on food security.

An important follow-up question is whether loss or waste reductions are a cost-effective way of alleviating food insecurity. Indeed, the cost of reducing food loss and waste, including comparing it to the costs of alternative measures to improve food security and nutrition, is an important factor in deciding on the desirability of such reductions. However, few studies look into the costs of various food loss or waste reduction measures and further research is needed to guide appropriate policy decisions.²⁹

An innovative study found that the reduction of post-harvest food losses by improving infrastructure lowers food prices and increases the amount of food available, thus improving food security. However, it is not as cost-effective as investments in agricultural research and development aimed at reducing post-harvest losses. Although both options offer high economic returns to investment, the returns for agricultural research and development are considerably higher than those for infrastructure improvements.²² In addition, it has been argued that the improvement in food security resulting from the reduction of post-harvest losses as estimated in the study may be exaggerated, as better infrastructure can also lead directly to an increase in food productivity and a drop in retail prices. Overall, the cost-effectiveness of improving food security by means of reducing post-harvest loss with infrastructure improvements is unclear.⁷⁶ There are currently no similar studies available on the cost-effectiveness of food waste reduction measures.

Another study into the relative effectiveness of various food security measures to meet the projected food demand in 2050 finds that food loss or waste reduction is least effective at boosting the availability of food worldwide.⁵ Yield gap closure through improved nutrient supply and management, enhanced irrigation efficiency and improved rainwater management are found to be most effective at increasing national food supplies, with an increase in national food production of 56–113 percent. A shift in diets towards more plant-based products is estimated to boost national food supply by 28–36 percent and food loss and waste reduction by 7–14 percent. The impact of a reduction in food losses or waste on food supplies varies widely from one country to another; the increases in supply range from 2.5 to 25 percent at the moderate implementation level (a 25 percent reduction in losses and waste), and from 2.5 to 100 percent at the high implementation level (a 50 percent reduction in losses and waste). ■

CONCLUSIONS

The impact of reductions in food losses and waste on food security and nutrition is not straightforward. Assuming that loss and waste reductions will automatically improve food security and nutrition or eliminate hunger, irrespective of location and cost, is incorrect. Indeed, the impact depends on the location, both geographically and along the supply chain, of the loss or waste reduction and of those who are food insecure. The desirability in terms of food security and nutrition of reduction measures depends on the cost-effectiveness of these measures compared to alternative measures. Note that a certain level of loss and waste is a necessary outcome of having enough buffer supplies to guarantee food security and adequate nutrition across time and space. An excessive reduction of these buffer supplies may jeopardize the stability of food supplies and prices and thus access to food.

A key question is where to reduce food losses or waste in order to obtain the most impact in terms of food security and nutrition. The optimal entry point for interventions depends on the context; however, general principles can offer some guidance.

In low-income countries with high levels of food insecurity, food losses are often a more pressing problem than food waste. Here, the reduction in food losses at the early stages of the food supply chain is most likely to have strong positive food security impacts, as its effects will be felt throughout the rest of the chain. The reduction of on-farm losses, which constitute a critical loss point in low-income countries, as demonstrated in Chapter 2, may significantly improve the food security status of poor smallholders; it may also boost supplies in local or national food markets, improving overall food security. Reductions in food losses or waste at other stages in the food supply chain can also have positive food security impacts. A reduction in the amount of food wasted by households, for example, improves households' food security status; the potential for improvement depends on the level of food waste.

The retail and consumption stages are typical loss points in high-income countries; however, overall food insecurity in these countries is

not extensive and reducing food losses or waste is unlikely to bring significant food security benefits. Pockets of food insecurity and malnutrition in these countries are most often associated with poverty. The recovery and redistribution of food may help alleviate food insecurity in these cases; however, wider social policies are necessary to address the underlying causes of food insecurity.

A reduction in the amount of food lost or wasted in high-income countries is unlikely to boost the availability of food in other countries with high levels of food insecurity. Indeed, such an impact is conditional on the possibility of transporting the recovered losses or waste to food-insecure groups abroad. Lower food prices resulting from waste reductions in high-income countries may be transmitted to countries with lower incomes via international markets; however, the size of the impact may not be large and will depend on a range of factors. Loss reductions in high-income countries may boost the competitiveness of food imported into lower-income countries through lower prices; this may benefit food-buying households in those countries, but negatively affect households that produce food.

There are currently no studies that demonstrate the effect of reductions in food losses or waste on people's nutrient deficiencies, though a few available studies estimate the potential effect of this. However, estimates of the effect of food loss and waste reduction on micronutrient deficiencies in children may be overstated because these are often caused by infections that reduce appetite and hamper nutrient utilization, rather than by a lack of food.^{49, 50} Nevertheless, reducing qualitative food losses or waste throughout the supply chain is likely to have a beneficial impact on nutrition in any country, as the availability of quality, nutritious and safe food increases.

Food loss and waste reduction is not necessarily the most cost-effective way of improving food security and nutrition. Increasing agricultural productivity through research and development has been found to be more cost-effective in this respect than reducing post-harvest losses. Meanwhile, broad efforts towards agricultural development may have positive side effects in terms of loss or waste reduction. ■

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Farmers working in a maize field using sustainable agricultural practices in Ngoma district.
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CHAPTER 5

FOOD LOSS AND WASTE AND ENVIRONMENTAL SUSTAINABILITY

Key messages

1 Reducing food loss and waste can contribute to feeding the world population in an environmentally sustainable manner as it helps to improve resource use efficiency and decrease the amount of greenhouse gases (GHGs) emitted per unit of food consumed.

2 To be environmentally effective, interventions to reduce food loss and waste need to consider where food loss and waste has the greatest impact on the environment – both in terms of food products and the stage of the food supply chain.

3 Food loss and waste reduction measures will ultimately have implications for the environment through lower food prices, which will reduce production and the associated negative environmental impacts.

4 Environmental improvements associated with reductions in food loss and waste will be difficult to target geographically when price signals are transmitted along geographically widespread supply chains.

5 When targeting land and water impacts, which are concentrated in primary production, policymakers must be aware that their food loss and waste reduction interventions are most effective in the early stages of the supply chain and in geographic proximity to the environmental impact.

6 When targeting GHG emissions, which accumulate throughout the entire food supply chain, policymakers must be aware that their food loss and waste reduction interventions will be most effective at the consumption and retail stage, independently of the location of the interventions.

FOOD LOSS AND WASTE AND ENVIRONMENTAL SUSTAINABILITY

Reducing food loss and waste is enshrined in SDG 12 on sustainable consumption and production – specifically in Target 12.3, which calls for the halving of food waste and reduction of food losses by 2030. It is also connected to the environmental dimension of the other SDGs, including SDG 6 on water and sanitation (Target 6.4 on the efficiency of water use), SDG 13 on climate action (Target 13.2 on the reduction of GHG emissions), SDG 14 on marine resources (Target 14.2 on protecting marine and coastal ecosystems) and SDG 15 on life on land (Target 15.1 on the conservation of ecosystems). The inclusion of food loss and waste reduction in the SDGs reflects the fact that producing food that is not eaten – whether lost in the field or wasted on a plate – not only diminishes the quantity of food available, but also constitutes a waste of economic and environmental resources.¹

This chapter explores the available evidence on the impact of food loss and waste on environmental sustainability and examines the potential for achieving environmental objectives through food loss and waste reduction. For this purpose, it first analyses the potential impact on the environment of food loss and waste reduction and discusses the factors to be taken into account in the formulation of reduction interventions with an environmental purpose. It then describes how food loss and waste actually affects the environment, depending on the stage in the supply chain where the losses or waste occur, the type of food, and – in some cases – the geographic location of the losses. After discussing the potential of food loss and waste reduction in achieving environmental objectives, the chapter then reviews the role of prices and the transmission of price changes in determining the actual environmental impact of reducing food loss and waste. It argues that interventions towards loss or waste reduction

should be formulated taking into consideration the location of the environmental damage and the extent to which the damage is local or global. Finally, the chapter looks at the cost-effectiveness of food loss and waste reduction to improve environmental sustainability and discusses possible trade-offs with other environmental objectives. ■

FOOD LOSS AND WASTE REDUCTION AND ENVIRONMENTAL SUSTAINABILITY

Feeding the world population in an environmentally sustainable manner will become increasingly challenging over the coming decades. The global demand for agricultural outputs is forecast to increase by 35–50 percent between 2012 and 2050 as a result of population and income growth.² Meeting this demand will further strain the world's natural resources and may cause considerable environmental damage, including climate change, land degradation, water scarcity, water pollution and loss of biodiversity (see [Box 26](#)). Against this background, food loss and waste reduction is seen as a way to improve the environmental sustainability of the global food system.

Attempts have been made to quantify the amount of resources wasted by producing food that is not eaten, based on average regional impact factors.

- Kummu *et al.* use data from the 2011 FAO study, as well as FAO Food Balance Sheets, to estimate the impact of food loss and waste on natural resources.^{3–5} The study finds that 24 percent of the global production of food »

BOX 26

THE MOST COMMON ENVIRONMENTAL FOOTPRINT INDICATORS FOR FOOD LOSS AND WASTE

Food loss and waste have three generally quantifiable types of environmental footprints: GHG emissions (carbon footprint); pressure on land resources (land footprint); and pressure on water resources (water footprint). These footprints may in turn affect biodiversity.¹

Carbon footprint

The carbon footprint of food is the total amount of GHG that is emitted throughout the food's life cycle, expressed in carbon dioxide (CO₂) equivalent.⁸ This amount includes all GHGs emitted during production, transportation, processing, distribution and consumption, as well as the emissions from waste disposal. Indeed, in many countries, most of the food that is lost or wasted is dumped untreated in controlled or uncontrolled landfill, where it releases GHGs. Some waste management systems, such as anaerobic digestion, can actually generate energy and thus provide indirect GHG savings.¹ However, waste management issues are beyond the scope of this report.

In both developed and developing countries, substantial GHG emissions occur during the primary production phase; this is where agricultural inputs are used, livestock is reared and soils are cultivated. GHG emissions further accumulate as food completes its life cycle, during processing, transportation, distribution, preparation and disposal.⁹ For this reason, the carbon footprint of food that is lost or wasted towards the end of the supply chain may incorporate significantly larger embedded levels of GHG emissions than food lost earlier on in the chain. Note that the carbon footprint of food losses or waste varies considerably from one type of food to another,ⁱ while also depending heavily on the characteristics of a country's food production system.¹

Land footprint

Competition for land is projected to intensify in the coming decades due to population growth, changes in diets and consumption patterns, and a growing demand for bioenergy. Most of the historic expansion of agricultural areas has come at the expense of

forests, which play an essential role in environmental sustainability.¹⁰ Land use is therefore of critical importance in terms of climate change, biodiversity and ecosystem services.

As yet, there is no generally applicable method to measure the entire land footprint of food production. The present report calculates the land footprint of food based on the surface of land needed to produce that food. Under this definition, the primary production stage accounts for nearly all land use, since other phases of a food product's life cycle, such as processing, do not occupy substantial land surfaces.¹ As in the case of carbon footprint, the land footprint of food also largely depends on the type of food being produced, as well as on the characteristics of the production system.

Water footprint

From the irrigation of crops and watering of livestock to aquaculture purposes, agriculture accounts for about 70 percent of total global water withdrawals;ⁱⁱ the remaining 30 percent is taken for industrial production and domestic water supply.⁶

The water footprint of a food product is a measure of all the freshwater used to produce and supply that product to its final consumer, at all stages of the supply chain.

The water footprint consists of three components that capture different types of water:

- ▶ blue water: groundwater or surface water;
- ▶ green water: rain; and
- ▶ grey water: water used to dilute pollutant concentrations to acceptable levels.⁸

Studies of the water footprint of food typically focus on the blue-water footprint, which depends on the type of food, as well as the characteristics of the production system.ⁱⁱⁱ Similar to the land footprint, most of the water used to produce and supply food is used on farm, for irrigation purposes, even though the processing of certain food products may also require significant quantities of water.^{1, 11}

ⁱ For information on the amount of GHG emitted per unit of agricultural product by country, see FAOSTAT, 2019.¹²

ⁱⁱ Water for the dairy and meat industries and industrial processing of harvested agricultural products is included under industrial water withdrawal.⁶

ⁱⁱⁱ See Mekonnen and Hoekstra for the water footprints of different food products and production systems.¹³

- » crops (in calories) is lost or wasted, accounting for a similar proportion of natural resources used in worldwide food crop production.
- Based on data from the 2011 FAO study, another FAO study that was published in 2013¹ estimated that:
 - i. The global carbon footprint of food loss and waste, excluding emissions from land use change, is 3.3 gigatonnes of carbon dioxide (CO₂) equivalent, corresponding to about 7 percent of total GHG emissions.
 - ii. The use of surface and groundwater resources (blue water) attributable to food lost or wasted is about 250 km³, representing around 6 percent of total water withdrawals.⁶
 - iii. Almost 1.4 billion hectares, equal to about 30 percent of the world's agricultural land, are used to produce food that is later lost or wasted.⁴
- Springmann *et al.* examine ways to ensure the environmental sustainability of food production until 2050.⁷ Food loss and waste reduction is one of the options considered.^{4, 5} Based on loss and waste percentages reported in the 2011 FAO study, Springmann *et al.* estimate that halving food loss and waste from 2010 to 2050 would reduce environmental pressures linked to agriculture by 6–16 percent, depending on the environmental dimension (GHG emissions, cropland use, blue-water use, nitrogen and phosphorus application), relative to the projected values for 2050. The report argues that food loss and waste reduction has a role to play as part of a broader package of interventions towards environmental sustainability, together with, for example, dietary change and technological improvements.

Estimates such as these suggest that food loss and waste reduction has the potential to improve the environmental sustainability of food systems significantly. However, aggregate estimates do not provide any indication as to which loss or waste reduction measures are most effective in environmental terms, nor do they distinguish between context-specific impacts of food loss or waste on the one hand, and broader, or even global, impacts on the

other. When thinking about water availability, for example, it may be difficult to foresee the geographic location of the impacts of a reduction of losses or waste. On the other hand, GHG emissions linked to food that is lost or wasted have worldwide repercussions independently of where the loss or waste occurs. ■

FOOD LOSS AND WASTE REDUCTION AND THE ENVIRONMENT – KEY QUESTIONS AND CONSIDERATIONS

As in the case of food security, the geographic location and stage in the supply chain of the loss or waste and of the intervention influence the intervention's impact in terms of environmental sustainability. Interventions towards food loss and waste reduction can therefore contribute towards reaching the targets of SDG 6, SDG 13, SDG 14 and SDG 15 if formulated with due consideration for the nature and location of the environmental impact per type of food product and the location in the supply chain of the loss or waste. In addition, the costs and trade-offs associated with different reduction interventions should be considered.

The following questions are essential to formulate suitable interventions towards food loss and waste reduction for environmental purposes:

► What is the environmental objective?

The objective is important since the carbon, land and water footprints are affected differently by food loss or waste depending on the food product, how it is produced, and the stage in the food supply chain where loss or waste occurs. The land and water footprints of food are concentrated at the primary production stage, although significant amounts of water may also be used during processing, whereas GHG emissions may occur and accumulate along the entire supply chain. GHG emissions per unit of food lost or wasted are therefore higher towards the retail and consumption stages of the chain.

- **To what extent do different food products contribute to food loss and waste, and what is their environmental footprint?**

The answer to this question may vary significantly across countries and regions due to differences in production, supply systems and socio-economic conditions. It will also depend on the environmental dimension under review. For example, while cereals and pulses may require significant amounts of water, the same may not be the case for land.

- **What is the magnitude of the food losses or waste, and what is the potential to reduce them, at various stages of the food supply chain?** The larger the food losses or waste are at the various stages in the food supply chain, the greater the potential to reduce them.⁴

- **What is the objective of the measure: improve resource use efficiency or reduce the overall amount of resources used?**

The reduction of food losses or waste improves resource use efficiency and allows more food to reach consumers while using the same amount of resources. Food loss or waste reduction may help meet the world's growing demand for food in a sustainable manner. However, improved resource use efficiency does not necessarily mean that fewer resources are used, or fewer GHGs emitted; these impacts depend on how the reduction in losses or waste influences food prices and thus the demand and supply of food.

- **Will the environmental impact of a reduction in food losses or waste be traceable back to a particular geographic location or will it be more diffuse?** In practice, it may be difficult to foresee the geographic location of the impacts of a reduction of losses or waste on land or water use. The environmental impact is indirect and depends on how food loss and waste reduction measures affect food prices and, through prices, the use of land or water for food production in different locations. GHG emissions have global ramifications, irrespective of where they occur, so the geographic location of reduction interventions is therefore irrelevant.

- **What are the costs of reducing food losses or waste at different points in different food supply chains?** The desirability of

reducing food losses or waste at specific points in the food supply chain also depends on the costs. A related question is: **Are there any trade-offs between different environmental objectives?** Reducing one type of footprint may lead to another type becoming larger. For example, improving packaging can reduce food loss and waste and its associated environmental impacts on land use, water use and GHG emissions; however, packaging also involves GHG emissions and an increase in the use of plastics. Designing solutions that minimize these trade-offs will be key in any strategy to reduce food loss and waste. ■

QUANTIFYING THE ENVIRONMENTAL IMPACTS OF FOOD LOSS AND WASTE

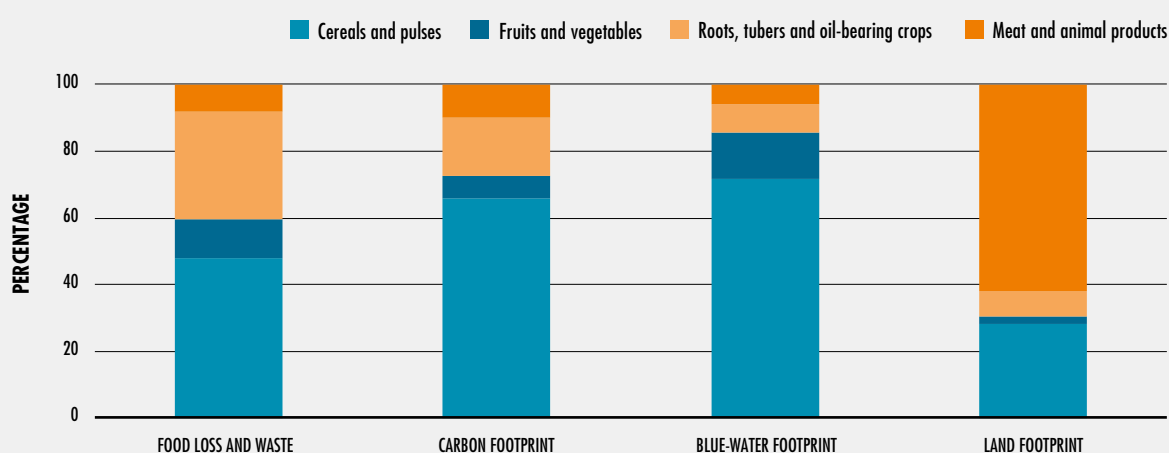
This section discusses empirical evidence related to the first three questions raised in the previous section. It attempts to quantify the environmental impacts of food loss and waste for various food products and regions, as well as for the different stages of the food supply chain. By doing so, the section demonstrates that the environmental effectiveness of an intervention aimed at reducing food loss or waste depends on the food product, as well as on the location – geographically and along the food supply chain – of the environmental damage.

The environmental footprints of food loss and waste across food products and regions

Policymakers interested in reducing the environmental impact of food loss and waste should first consider which environmental dimension to target (carbon, land or water) and which food products contribute most to that dimension's footprint when lost or wasted.

Figure 13 provides estimates of the relative contribution of the main food groups to overall global food loss and waste in terms of quantities (first bar on the left), as well as to the associated carbon, blue-water and land footprints (second, third and fourth bars). Note that the blue-water

FIGURE 13
RELATIVE CONTRIBUTIONS OF THE MAIN FOOD GROUPS TO OVERALL FOOD LOSS AND WASTE AND THEIR CARBON, BLUE-WATER AND LAND FOOTPRINTS



Note: The environmental footprints are calculated by multiplying the amount of food lost and wasted by its environmental impact factors. The carbon, blue-water and land impact factors were taken from FAO (2013), which provides environmental impact factors for different products, regions and supply chain stages.¹ For a breakdown of the impact factors by region and food group, see Tables A7–A9 in the Statistical Annex. The carbon impact factor expresses tonnes of CO₂ equivalent emitted, the land impact factor indicates hectares of land used, and the blue-water impact factor indicates cubic metres of water used, all per tonne of food lost or wasted. The stacked bars present the relative contribution of a food group to total food loss and waste and to each of the environmental footprints of food loss or waste. The estimations of food loss and waste differ from the ones presented in Figure 4 with respect to the inclusion of the retail level, the share of food loss and waste being measured in terms of quantity (rather than economic value), and the use of loss and waste data for only those commodities for which an impact factor was available. Thus, food products that do not belong to any of the groups included in the figure (e.g. coffee beans) are excluded from the graph due to the lack of data for impact factors, despite contributing around 20 percent to food loss and waste. These data refer to 2015.

SOURCE: FAO, 2013 and 2019.¹⁴

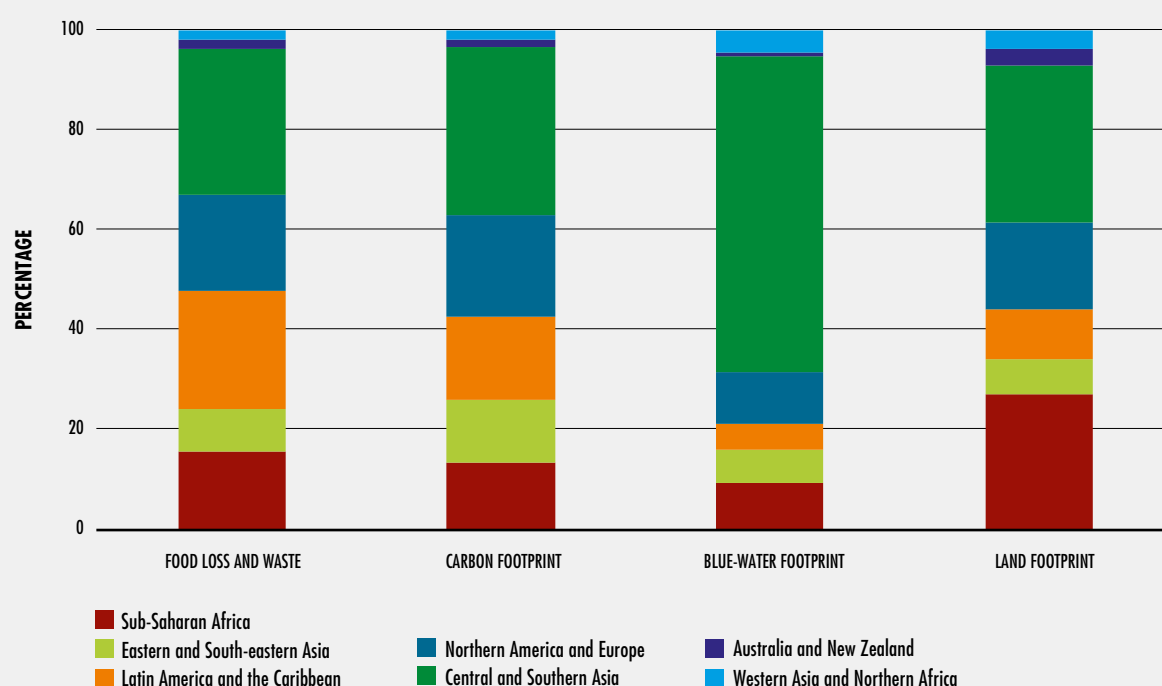
footprint considers the primary production stage only, ignoring water used during processing. The estimates include loss and waste from on farm post-harvest up to the retail level, excluding consumption. Preharvest and harvest losses are also excluded. Since the figure is based on worldwide averages, country-specific data for particular supply chains may differ from these averages. Despite these caveats, **Figure 13** presents a general indication of which types of food products should be targeted if food loss and waste reduction is to contribute to environmental sustainability.

As illustrated by the first bar on the left of **Figure 13**, cereals and pulses account for the largest share of food loss and waste in quantity terms, followed by roots, tubers and oil-bearing crops, and then fruits and vegetables. The contribution of meat

and animal products to overall food loss and waste is limited; however, their contribution to the land footprint of food loss and waste is not. Indeed, meat and animal products account for over 60 percent of the total land footprint (last bar on the right). This percentage reflects the fact that livestock production requires substantial amounts of agricultural land to produce animal feed or for grazing.¹ Any interventions that aim to reduce the land footprint of food losses or waste should therefore focus on this product group.

If the aim of an intervention is to address water scarcity, then cereals and pulses should be targeted as a product group, followed by fruits and vegetables. Together, these two categories account for nearly 90 percent of the water footprint of total food loss and waste. This percentage reflects the fact that a significant

FIGURE 14
RELATIVE CONTRIBUTIONS OF REGIONS TO OVERALL FOOD LOSS AND WASTE AND THEIR CARBON, BLUE-WATER AND LAND FOOTPRINTS



Note: The data in the figure cover the following food groups: cereals and pulses, fruits and vegetables, roots, tubers and oil-bearing crops, meat and other animal products, and “other” products. The stacked bars present the relative contribution of a region to total food loss and waste and to each of the environmental footprints of food loss or waste. Oceania (apart from Australia and New Zealand) is excluded from the graph due to its negligible contribution to food loss and waste (less than 1 percent). The estimates of food loss and waste differ from the ones presented in Figure 3 with respect to the inclusion of the retail level and the removal of an economic weight. These data refer to 2015.

SOURCE: FAO, 2013 and 2019¹⁴.

share of irrigation water is used to produce these crops, especially wheat, rice and maize.¹⁵

The livestock sector contributes relatively little to the blue-water footprint associated with food loss and waste. This may be explained by the fact that the data on loss and waste focus mostly on milk and eggs and less on meat and other animal products, which may have a larger blue-water footprint.¹⁴ Global average blue-water footprints are estimated at 86 m³ per tonne of milk, 244 m³ per tonne of eggs and over 500 m³ per tonne of beef or sheep meat.¹³ Another explanation is that the *average* blue-water footprint of meat and animal products incorporates the footprint of livestock systems that do not use irrigated feed grains.

Meat and animal products from systems that use feed produced on irrigated fields may well have a larger water footprint than other food groups.⁸

The relative contribution of meat and animal products to total GHG emissions associated with food loss and waste is limited, due to the limited share of these products in total food loss and waste, but the carbon footprint per tonne of meat and animal products is the largest of all food groups, with the exception of cereals and pulses. Indeed, emissions of methane by ruminants such as cattle, sheep and goats account for the bulk of agricultural GHG emissions in CO₂ equivalent, followed by emissions from feed production and manure management.

FIGURE 15
OVERVIEW OF THE MAIN RESULTS OF FAO'S FOOD WASTAGE FOOTPRINT STUDY, 2013

	LARGEST FOOTPRINT(S)	REGIONS MOST IMPACTED	KEY FINDINGS
MEAT 	Carbon and land	High-income regions and Latin America	Loss and waste volumes are relatively low in all regions. Nevertheless, meat is a major land and carbon hot spot.
CEREALS 	Carbon, land and blue water	Asia	Rice is an environmental hot spot due to its significant methane emissions during production and its high levels of food loss and waste.
FRUITS 	Blue water	Asia, Latin America and Europe	Fruit is a blue-water hot spot, not so much due to its blue-water intensity, but rather to the high percentage of fruits lost or wasted.
VEGETABLES 	Carbon	Industrialized Asia, Europe and Southern and South-eastern Asia	Vegetables are a carbon hot spot due to the high percentage of vegetables lost or wasted. The carbon intensity of vegetables varies between regions.
STARCHY ROOTS 	Although lost and wasted in high volumes in sub-Saharan Africa, Europe and industrialized Asia, starchy roots have a low environmental impact due to their low carbon, water and land intensities.		

Note: Due to data limitations, FAOSTAT, in its Food Balance Sheets, groups together a great number of fruits under the category "other fruits"; it is therefore impossible to analyse the hot spot of "fruits" in greater detail, i.e. per individual crop. "Industrialized Asia" includes China, Japan and the Republic of Korea.

SOURCE: FAO, 2013¹

The environmental footprint of a given food product varies across regions and countries, *inter alia*, due to differences in crop yields (see Figure 14). This is particularly true for water and land footprints. Central and Southern Asia, for example, are the largest contributors to overall food loss and waste and account for over half the global blue-water footprint of food loss and waste. Latin America and the Caribbean, on the other hand, despite representing more than 20 percent of total food loss and waste, account for only 9 percent of the blue-water footprint. These outcomes are in line with the results of a 2013 FAO study on the footprint of food wastage, which identified cereals, especially wheat and rice, as the main contributors to the blue-water footprint of food loss and waste in Asia (see Figure 15 for key findings).¹

Averages mask the fact that the same food product can have different blue-water footprints depending on the type of production system, which varies across geographic locations. A crop grown using irrigation has a larger blue-water footprint than the same crop grown under a rainfed system. Thus, geographic location is an important consideration when targeting interventions aimed at reducing the blue-water footprint.

The environmental footprints of food loss and waste at different stages in the supply chain

The environmental effectiveness of interventions to reduce food losses or waste depends not only on the type of food product and the geographic location, but also on where along the supply chain food is lost or wasted.

In fact, even though all stages of the food supply chain offer scope to mitigate the environmental impacts of food loss and waste, the extent of this scope at the various stages of the supply chain varies according to a country's level of economic development and the environmental dimension targeted. In industrialized countries, as most food is wasted towards the end of the food supply chain, targeting consumer waste may bring about the largest reductions in food loss and waste and the environmental damage it causes. In developing countries, reduction measures that target on-farm losses may be most effective in reducing the environmental footprints of food loss and waste.

Interventions that aim at that stage in the supply chain where *most food* is lost or wasted are not necessarily the most effective in mitigating the environmental impacts of food loss and waste. The following paragraphs demonstrate that interventions should also consider the stage in the supply chain where *environmental footprints are largest*.

For instance, the carbon footprint of food loss and waste follows a pattern throughout the various stages of the food supply chain quite different from that of land or water footprints. Hence, the location of reduction measures that aim to reduce the carbon footprint should not, in principle, be the same as those aiming to reduce water scarcity or land degradation. Indeed, GHG emissions embedded in a food product tend to increase as the product moves along the supply chain and the accumulated contribution of each stage in the chain is larger than the preceding stage. This implies that a unit of food lost or wasted at the wholesale or retail stages has a larger carbon footprint than a unit lost on farm, especially in high-income countries. The accumulation is much less pronounced for land and blue-water footprints, where the bulk of the environmental impact occurs in the agricultural production phase.

It follows that if the main objective of measures towards food loss and waste reduction is to reduce GHG emissions, the greatest impact per unit of food loss or waste avoided is at the consumption stage, where products incorporate all GHG emissions of the previous stages. If, on the other hand, the main objective is to reduce

the use of land or water, interventions closer to the primary production stage may prove most effective, as subsequent stages will add little to the environmental damage.

Contrary to GHG emissions, environmental problems caused by the unsustainable use of land or water are mostly specific to a geographic location. This is another reason why it is often advisable to intervene in, or close to, the primary production stage to remedy these problems. Interventions further along the supply chain may be less effective in remedying a location-specific environmental problem, as not all products targeted originate from the problem area. In other words, measures towards food loss or waste reduction will improve the countrywide *average* blue-water and land use efficiency no matter where they are implemented. However, improving resource use efficiency where it matters most requires an understanding of the extent to which land and water footprints are determined by geographic location, as well as the location in the supply chain of food losses or waste.

Box 27 illustrates the variability of impact factors for each environmental footprint by focusing on a single product, maize, in four different regions. Data aggregation across commodities, countries and regions blurs some of the specificities of footprints for particular products or geographic locations along the supply chain, such as the cumulative effect of the carbon footprint. But looking at a single product provides more detailed insight into these specificities. ■

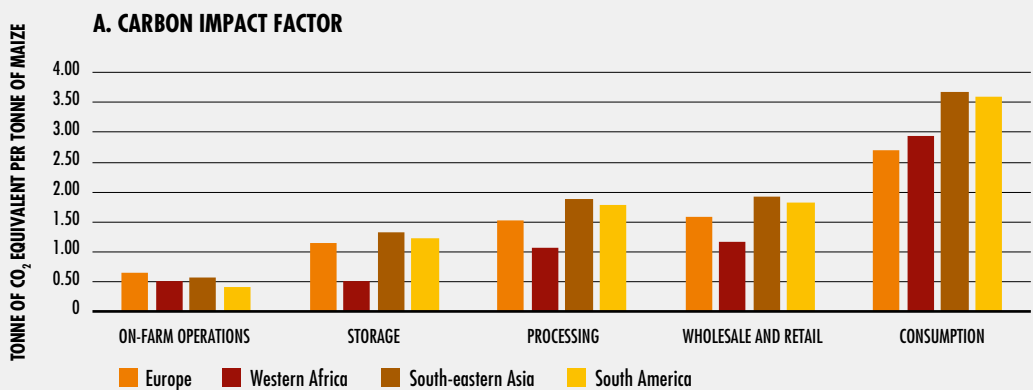
FROM POTENTIAL TO ACTUAL IMPACT ON NATURAL RESOURCE USE AND GHG EMISSIONS – THE ROLE OF PRICES

So far, the chapter has discussed the potential for reducing the different environmental footprints of food loss and waste based on the magnitude of food loss and waste and its environmental impact across commodities and locations, both geographically and along the food supply chain.

BOX 27 ENVIRONMENTAL FOOTPRINTS OF FOOD PRODUCTION ALONG THE SUPPLY CHAIN – THE CASE OF MAIZE

The figures in this box present the carbon, water and land impact factors for maize in Europe, Western Africa, South-eastern Asia and South America. GHG emissions clearly accumulate as maize moves along the food supply chain (Figure A). Consequently, the consumption stage has the largest carbon footprint. Here all the emissions throughout the supply chain are embedded in the product. The land and water footprints of losses or waste of maize are the same at all stages in the supply chain, assuming that land and blue water (Figures B and C) are used solely during the primary production phase.

The figures below show that both GHG emissions and natural resources used for maize production differ from one region to the other. The production of a tonne of maize causes more GHG emissions in South-eastern Asia and South America than in other regions. It requires most land in Western Africa, especially in comparison to Europe, where land use efficiency appears to be highest. However, maize production in Europe is much more water-intensive than in the other regions, most likely because of the more widespread use of irrigation in Europe.



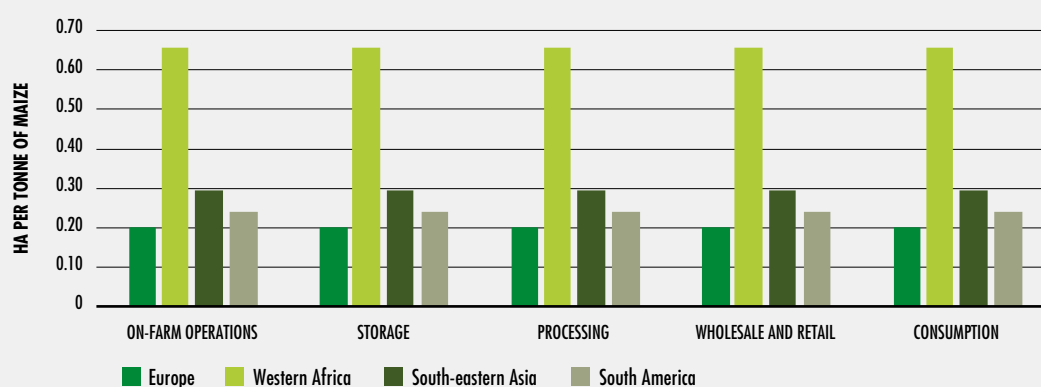
The extent and location where reductions in food losses or waste will actually lead to reduced environmental footprints is a more complex question. This is because the impact of any intervention to reduce food losses or waste somewhere in a supply chain will depend on how prices for suppliers and consumers change both along the supply chain and across geographic areas. These price transmission effects are crucial to how the impacts play out.

Reducing food loss and waste means that more food can reach the consumer using the same

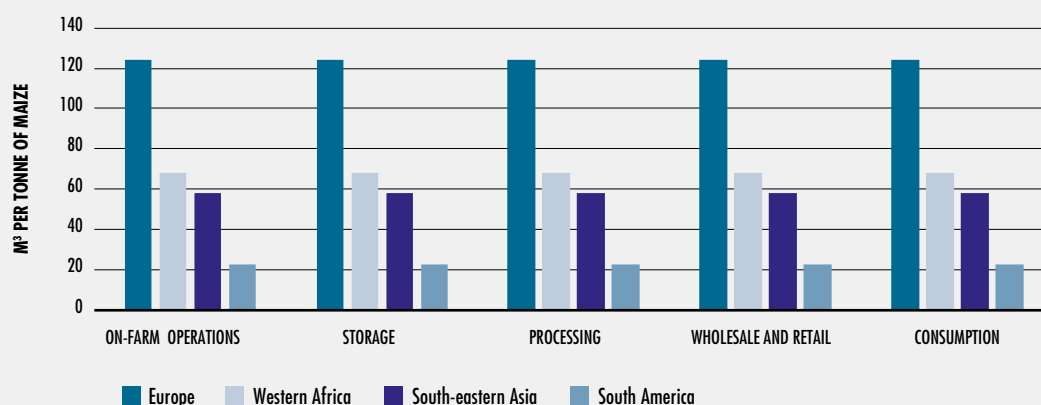
amount of natural resources and emitting the same amount of GHGs. Likewise, it means the same amount of food can reach the consumer using fewer natural resources and emitting fewer GHGs. In other words, natural resources will be used more efficiently and GHG emissions per unit of food consumed will be reduced. Still, an increase in resource use efficiency or a decrease in GHG emissions intensity does not necessarily translate into a decrease in the total amount of resources used and GHGs emitted. The extent to which resource use and GHGs are reduced will depend on how prices change as a result of

BOX 27
(CONTINUED)

B. LAND USE IMPACT FACTOR



C. BLUE-WATER IMPACT FACTOR



Note: Regions were selected based on the availability of region-specific data for impact factors. In this case, on-farm operations include preharvest, harvest and post-harvest operations.
SOURCE: FAO, 2013¹

the reduction in food loss and waste and how suppliers and consumers react to those price changes. In theory, a decrease in the amount of food lost by producers or suppliers will boost the supply of food. Similarly, a decrease in food wasted by consumers will dampen the demand for food. In both cases, since more food is available, food prices fall. This reduction in prices is transmitted through the food supply chain.

To the extent that markets are closely integrated and interdependent, the price changes will also be transmitted to a greater or lesser extent

across geographic locations. Assuming that individual producers cannot influence prices, the fall in prices will incite producers to reduce their output, ultimately leading to reduced use of natural resources and lower GHG emissions. However, there may be counterbalancing second-round effects if the reduced food prices lead to an increase in demand. This, in turn, would lead to higher food prices and a renewed increase in supply and natural resource use. This may counterbalance, at least in part, the initial impact. The exact outcome will be an empirical question.

In contrast, in situations where the adoption of loss reduction measures are the result of regulation, the increased costs associated with reducing food loss and waste may have a limiting effect on supply in combination with an increase in prices. As production declines, natural resources will be conserved and fewer GHGs emitted.

The following section will look more carefully at the role of price changes and their transmission, which has important implications in terms of where to intervene to reduce food loss and waste based on environmental objectives. The first part looks at price transmission along the food supply chain, while the second part focuses on transmission across geographic areas. The third part presents empirical evidence. It emerges that the environmental effectiveness of an intervention to reduce food loss or waste depends on the location of the environmental damage geographically and along the supply chain, as well as on the impact of the reduction on the prices of inputs and outputs.

Price transmission and the location of environmental damage along the food supply chain

A reduction in food losses or waste at a particular location in the supply chain affects prices both upstream and downstream from that location, assuming the reduction is large enough to have an impact on prices. How those price changes are transmitted throughout the supply chain to reach the operators causing the damage determines the environmental outcome of the reduction.

The bulk of the land and blue-water footprint of food losses or waste originates in the primary production stage (see [Box 27](#)). Therefore, a reduction in food losses or waste that depresses farmgate prices and thereby induces producers to scale back their production – and thus their use of natural resources – will lead to an environmental improvement, irrespective of the location along the supply chain of the losses or waste.

Contrary to the land and blue-water footprints, which originate above all in the primary production stage, the carbon footprint of food losses or waste grows incrementally as food progresses along the supply chain.

Operators located well after the primary production stage may still produce considerable GHG emissions. A reduction in food losses at an early stage of the supply chain that lowers the costs of inputs for those operators may induce them to expand their output, and as more food moves throughout the supply chain, the eventual result would be increased GHG emissions.

This is illustrated in [Figure 16](#). Here, food incorporates the accumulated emissions of all the preceding stages of the supply chain, meaning that a unit of avoided food loss or waste has the strongest impact on GHG emissions at the retail and consumption stages. Therefore, reduction measures aimed at reducing the carbon footprint of food loss and waste should intervene at the later stages.

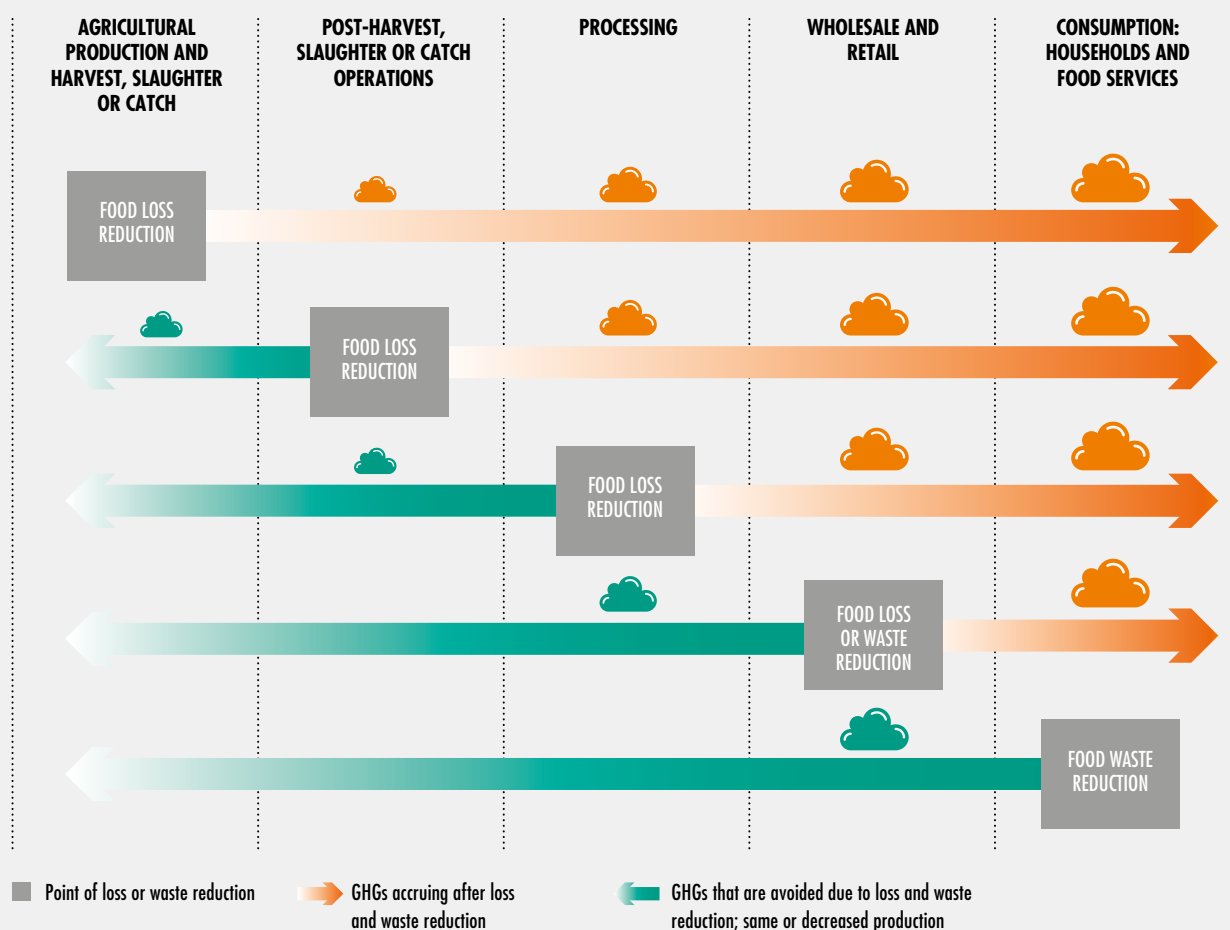
Price transmission and the geographic location of environmental damage

In the previous part it was pointed out how price changes associated with a reduction in food loss and waste are transmitted throughout the supply chain to reach the operators causing the environmental damage, and how this determines the environmental outcome of the reduction. A similar reasoning can be applied with respect to the geographic location where the environmental damage occurs.

In fact, if the reduction of food loss and waste occurs close to the location of the environmental damage, the resulting change in prices is likely to be transmitted more strongly to those causing the damage; hence, it will be more effective at inducing those actors to adjust their output and thus resource use. To illustrate, if the environmental objective being pursued is water-scarcity reduction, decreasing food losses in water-scarce areas near or at primary production, where the bulk of water resources are used, may prove the most effective. Indeed, farmers using those same water resources would feel the resulting fall in prices more strongly, therefore discouraging production and resource use.

If, instead, interventions occur further away from those actors, price effects must ripple through the supply chain to reach them but may be weakened by the time they do so, lowering the

FIGURE 16
CARBON IMPACT OF FOOD LOSS AND WASTE REDUCTION ALONG THE FOOD SUPPLY CHAIN



SOURCE: FAO

incentive for output and resource use adjustment. While they can impact on natural resource use across a system, they may well fail to target specific critical areas. This is important for environmental harm that is highly localized, as is often the case for land and water stresses. To build on the previous example, if reduction measures occur instead at the wholesale level, policymakers risk not reducing water scarcity in water-scarce regions, as food products may derive from many geographically dispersed farmers who do not necessarily suffer from water scarcity. Hence, by the time prices are transmitted to farms in water-scarce regions, the diluted

price effect may not be strong enough to induce farmers to adjust production and resource use. Price transmission is likely to be stronger between suppliers who are directly linked, as opposed to indirectly through other agents.

How changes in prices resulting from a reduction in food losses or waste are transmitted along the supply chain also depends on the geographic spread of that chain. In a geographically concentrated supply chain, a loss or waste reduction targeting a local environmental problem is likely to “hit” its target as price changes are transmitted clearly and directly

between suppliers and consumers. In supply chains with a wide geographic spread, food at the consumption stage may be sourced from many different locations, including other countries. Here, reductions in consumer waste are unable to target location-specific environmental damage; this must be done through reduction interventions close to the location of the damage, geographically and in the supply chain.^q

The dilution of the price effects of loss or waste reductions – for example, from waste reduction by consumers back to the farmer – may not be an issue for non-location-specific environmental damage, such as GHG emissions. Here, a small drop in production by a large number of farmers following a diluted price signal will help mitigate climate change. In other words, the geographic location of interventions to reduce food losses or waste does not matter for policymakers aiming to reduce GHG emissions, which are a global concern.

In conclusion, while irrelevant for GHG emission reductions, location is important for interventions aimed at alleviating localized environmental harm, for instance to land or water resources. However, in these cases, it may well be advisable to address location-specific environmental stresses through measures targeted directly at those stresses, rather than by reducing food loss or waste.

Empirical evidence on the effects of price transmission across sectors and regions

The impact through prices of a reduction in food losses or waste on food demand and supply depends on how the price changes affect actors within and across markets and countries. **Box 28** illustrates the complexities of these effects, based on the results of an economy-wide modelling framework. It shows how a global 25 percent reduction in food losses at the primary production and processing stages reduces the use of land but fails to bring about any significant reduction in GHG emissions at the global level. This result

^q In certain cases, such as pollution of large watersheds, water issues can no longer be considered “local”. For example, agricultural runoff into the Mississippi River causes eutrophication in the Gulf of Mexico. Given the scale of the Mississippi River Basin, even an untargeted campaign towards food loss or waste reduction may mitigate this damage.

confirms that interventions early on in the supply chain may reduce land stress, while GHG emissions should be addressed further down the chain. Although the modelling framework does not account for income or population growth, its results are nevertheless very relevant in light of the growing demand for agricultural products expected over the coming decades.¹⁶

Alongside the issue of where in the supply chain reductions in food loss occur, further complexity is added when considering interactions between different parts of the food system, as well as with other sectors. In this respect, another study finds that reducing assumed food losses from 20 percent of production to 5 percent would decrease agricultural prices by about 4 percent, which in turn would boost the production of meat and biofuels benefiting from lower agricultural input prices. Overall, the reduction in loss and waste would cut the use of agricultural land by 4.5 percent, reducing the increase in GHG emissions over the 2000–2020 period from an estimated 25 percent under a business-as-usual scenario to less than 8 percent. However, the study does not assess the feasibility of specific measures for food loss or waste reduction, nor does it outline how those measures could be implemented in practice.¹⁶ ■

FOOD LOSS AND WASTE REDUCTION IN THE BROADER CONTEXT OF SUSTAINABILITY – COMPARATIVE EFFECTIVENESS AND TRADE-OFFS

The environmental sustainability of the global food system is put at risk by the increasing demand for food from a growing world population, as well as by dietary changes associated with rising incomes. Against this background, food loss and waste reduction is one of various possible interventions to ensure that 9.7 billion people are fed in an environmentally



BOX 28

THE IMPACTS OF A 25 PERCENT REDUCTION IN GLOBAL FOOD LOSSES ON AGRICULTURAL LAND USE AND GHG EMISSIONS

The effect of a reduction in food losses or waste on land and water use and GHG emissions is determined by how the price changes caused by that reduction are transmitted throughout the supply chain and the wider economic system.

Wageningen University and Research used a global, economy-wide model known as MAGNET to simulate a 25 percent reduction in losses at the primary production and processing stages based on FAO's most recent food loss estimates (see also Box 25).ⁱ

This reduction in losses can be represented as changes in productivity that increase global production by 4.3 percent, of which 2 percent is at the primary production stage and 2.3 percent at the processing stage. The impacts of the reduction on agricultural land use and GHG emissions are summarized in the table in this box.

The study shows that a 25 percent loss reduction at the primary production and processing stages has a

very limited effect on global GHG emissions (-0.07 percent). Two separate phenomena may explain this result. First, GHG emissions accumulate as food moves along the supply chain. A loss reduction early in the chain means that more food reaches the retail level, which boosts aggregate GHG emissions. A reduction in consumer food waste comparable to the reduction in losses earlier in the supply chain, as simulated in the model, can be expected to have a greater impact on GHG emissions. Second, a reduction in losses may result in the reallocation of resources to other sectors. If these sectors emit more GHGs than the one where the food loss is avoided, overall GHG emissions may rise.

Both processes are at the root of increases in GHG emissions in sub-Saharan Africa and Latin America and the Caribbean resulting from the simulation. These occur in spite of decreased

ENVIRONMENTAL IMPACTS OF A 25 PERCENT REDUCTION IN FOOD LOSSES AT THE PRIMARY PRODUCTION AND PROCESSING STAGES, PERCENTAGE CHANGE

	Economic impact	Environmental impact					
	GDP	Agricultural land use			GHG emissions		
Global	0.12	-0.68			-0.07		
By region		Total effect	Contributions		Total effect	Contributions	
			Domestic	Foreign		Domestic	Foreign
Sub-Saharan Africa	0.57	-1.29	-0.62	-0.67	0.26	0.58	-0.33
Central and Southern Asia	0.22	-0.41	-0.24	-0.17	-0.33	-0.06	-0.27
Eastern and South-eastern Asia	0.19	-0.49	-0.29	-0.20	-0.10	-0.02	-0.07
Western Asia and Northern Africa	0.10	-0.33	-0.12	-0.22	-0.09	0.03	-0.12
Latin America and the Caribbean	0.20	-1.18	-0.41	-0.77	0.10	0.36	-0.26
Northern America and Europe	0.06	-0.30	-0.11	-0.19	-0.05	0.04	-0.08
Oceania	0.09	-0.16	0.04	-0.19	-0.09	0.71	-0.80

NOTE: "Domestic" refers to the impact of loss reductions within a region on the region itself; "Foreign" refers to the impact on a region of reductions in losses occurring in other regions.

BOX 28
(CONTINUED)

resource use intensity per unit of food reaching the consumer. Regions showing a significant economic expansion following the loss reduction are more likely to experience a net increase in GHG emissions (e.g. sub-Saharan Africa). Changes in GHG emissions that result from the shifting of resources between sectors are typically beyond the scope of any policies that target the food system and are difficult to predict.

The reduction in food losses in one country may affect GHG emissions in another. A reduction in losses overseas may make imported foods cheaper, resulting in a substitution away from domestically produced foods, thereby causing a drop in domestic GHG emissions.

The model predicts a decrease of nearly 0.7 percent in agricultural land use following a 25 percent reduction in food losses at the primary production and processing stages. While still limited, this impact is considerably larger than for GHG emissions and may serve to counterbalance the projected increase in the demand for agricultural land associated with growing food requirements over the coming decades. The background paper of the study demonstrates that interventions close to the primary production stage are more effective at reducing the demand for agricultural land than interventions at the processing stage, due to the stronger transmission of price changes between directly linked producers and buyers (not shown in the table).

According to the model, both domestic and foreign loss reductions decrease the use of agricultural land in all regions, except for Oceania, where domestic food loss reductions result in a slight increase in land use. Foreign loss reductions tend to have a stronger limiting impact on land use; only in Central and Southern Asia and in Eastern and South-eastern Asia is the effect of domestic reductions stronger. The significant impact of foreign food loss reductions on land use is explained by the substitution of imports for domestically produced food (see also “availability” in the table in [Box 25](#)), which

reduces the pressure on domestic land. Domestic loss reductions, on the other hand, may have the opposite effect on the use of land. Indeed, improved productivity following a loss reduction makes domestic foods more competitive relative to imported foods, which may provide a boost to domestic production. The resulting increase in land use works against the initial limiting effect on land use of domestic food loss reductions; in some cases, the net result may be a heavier land footprint. The policy implication is that reducing food loss in one region is more likely to have an effect on demand for agricultural land outside of that region than inside it.

There are a number of caveats to the interpretation of the simulation results for policy purposes. First, the model assumes that loss reductions are the result of the voluntary adoption of measures that lower production costs and thus boost profits. However, some loss reduction measures may cause production costs to increase, for example in the case of taxes or bans imposed by law. This negatively affects the competitiveness of domestically produced food, reducing GHG emissions and domestic land use, but may increase environmental damage in other regions.

Second, the results of the simulation depend on the degree to which price changes are transmitted across regions. This transmission determines whether loss reductions have an impact on GHG emissions and land use in locations far from those where the reductions take place. The degree to which price changes are transmitted across regions depends on the type of food product, the structure of the supply chain that brings the product to consumers and whether the product is traded between regions. How price changes will be transmitted across regions is not straightforward to predict. The results of the model as to the domestic effects of loss reductions are therefore more robust than those that concern the effects of foreign loss reductions. For this reason, the model’s results as to domestic effects on the one hand, and foreign effects on the other, are presented separately in the table.

ⁱ FAO’s Statistics Division provided food loss estimates by food group, country group and supply chain stage. In the simulation, food loss reductions vary across food products, regions and supply chain stages. However, due to differences between FAO’s food loss estimation methodology and the structure of MAGNET, the supply chain stages included in the simulation are limited to primary production and processing stages; the simulation does not cover other supply chain stages, such as storage, transportation, wholesale and retail.
SOURCE: Kuiper and Cui, 2019¹⁷

BOX 29

WATER USE IN THE PRODUCTION OF MANGOES IN AUSTRALIA – TARGETING RESOURCE USE EFFICIENCY VERSUS ACTUAL WATER USE

A study of the use of water to produce mangoes in Australia analyses the environmental impacts of three possible interventions for water saving.²¹ Of these, reducing loss and waste is found to be the most effective in terms of resource use efficiency. Halving wastage at the distribution and consumption stages would cut the water footprint of 1 kg of fresh mango from 87 to 57 litres, a reduction of 34 percent. A reduction of 40 percent of the water used to irrigate half of Australia's mango orchards would reduce the water footprint of each

kilogram of fruit by 18 percent. An expansion of mango production in water-abundant regions by 20 percent would reduce the average water footprint of 1 kg of fruit by 11 percent. This is an interesting case, showing the difference between resource use efficiency and actual use. Reducing waste guarantees more efficient use of resources but not necessarily a comparable reduction in use, while reducing irrigation acts directly on the amount of irrigated water used but at a smaller gain in resource use efficiency.

» sustainable way in 2050.² By improving resource use *efficiency*, food loss and waste reduction can help boost food supplies without aggravating the damage inflicted on the environment, even if overall resource use (or GHG emissions) and environmental impacts are not reduced (see **Box 29** for an example).

The environmental impacts of food loss and waste reduction as compared to those of other interventions towards sustainability

The available evidence suggests that while food loss and waste reduction can contribute towards environmental sustainability, it must be complemented by other interventions to significantly alleviate the damage inflicted by the food system on the environment. Among these other possible interventions are improving agriculture technology or promoting dietary change.¹⁸

Springmann *et al.* estimate the impacts of a range of possible interventions aimed at reducing the environmental footprint of the global agrifood system.^{7, 19} The study delineates baseline trajectories for GHG emissions, cropland and blue-water use and the application of nitrogen and phosphorus in the global food system until

2050. It then assesses the impact by 2050 of a number of interventions: reductions in food loss and waste by 50 and 75 percent respectively; moderate and strong technological progress in agriculture; widespread adoption of more plant-based (flexitarian) diets; and a combination of these interventions, implemented moderately and intensely. The interventions are different in nature. Even in this case, they could be comparable if there was a sense of the costs of implementing them, but this information is not provided by the study. Although the results of the different interventions are not comparable in practical terms, they can provide a sense of the order of magnitude of the environmental effect of interventions that seem within reach in the coming decades.

The study finds that of the single interventions analysed, improved technology is the most effective intervention towards reducing cropland, blue-water and fertilizer use. A reduction in food loss and waste by 50 or 75 percent is the second most effective intervention in this respect, cutting cropland use by 14–21 percent, blue-water use by 13–19 percent, nitrogen by 16–24 percent and phosphorus by 15–23 percent. Dietary change is found to be least effective in terms of cropland, blue-water and fertilizer use. In terms of the impact on climate change, food

loss and waste reduction is the least effective at reducing GHG emissions, resulting in a reduction of 6–9 percent by 2050. Dietary change brings about a reduction of 29–52 percent in global GHG emissions, making it the most effective measure.

Note that the simulations in Springmann *et al.*, aside from not factoring in the costs associated with the interventions, do not consider the institutional and organizational changes necessary to formulate and implement them. Indeed, the barriers to adopting certain changes may be considerable, e.g. in the case of technologies and practices to mitigate and adapt to the effects of climate change.²⁰ On the other hand, reducing food loss and waste has one possible advantage over other options for reaching environmental objectives such as technological change or dietary change: it can save people money. Institutional and organizational aspects are facilitated when there is a private motivation for reducing loss and waste, both for businesses that save on inputs and for consumers saving money by avoiding wastage.

All in all, food loss and waste reduction will not resolve all environmental problems associated with food production and must be complemented by other improvements, such as technological progress and dietary change, to ensure the environmental sustainability of the food system. While assessments at the global level provide an indication of the order of magnitude of the impacts of these improvements, more detailed information is needed to identify the most effective and cost-effective measures. Gathering such detailed information will constitute a major challenge for researchers in coming years.

Trade-offs between the environmental impacts of food loss and waste reduction

While the reduction in food losses or waste is by and large beneficial for the environment, certain reduction measures may add to environmental stresses. Improvements in cold storage facilities aimed at loss or waste reduction, for example, may increase the use of energy in the food system and thus GHG emissions.²²

Ensuring the availability of safe, quality food around the world, especially in the face of climate change, requires adequate cold chain facilities.²² In 2009, the International Institute of Refrigeration estimated that if developing countries acquired the same cold chain capacities as those in developed countries, over 200 million tonnes of food would be saved annually. According to the same study, this corresponds to roughly 14 percent of consumption in these countries.²³

Improving the energy use efficiency of cold chain technologies may help reduce GHG emissions from refrigeration. An example is the replacement of current refrigerators, including those in homes, with greener alternatives.^r Box 30 illustrates how implementing clean-energy technologies may help save food, while at the same time reducing GHG emissions.

Adequate packaging may prevent food losses or waste by protecting and extending the shelf life of food products. The use of reusable plastic crates instead of wooden crates or bamboo baskets for transporting fruits and vegetables in the Philippines, for example, was found to reduce losses at low cost.²⁷

While packaging may help avoid losses or waste, its production generates GHG emissions. The packaging itself also becomes waste at the end of its life cycle unless recycled.²⁸ Packaging accounted for 36 percent of the total 400 million tonnes of plastic produced in 2015 and 47 percent of the total 300 million tonnes of primary plastic waste.²⁹ It is estimated that 40 percent of all packaging material, plastic and other, produced in 2007 (as measured in USD) was to package food.³⁰

Packaging is increasingly blamed for having one of the highest environmental footprints in the food system. However, assessments of its

^r Household refrigerators are often overlooked as part of the cold chain, even though it is estimated that there are 1 billion domestic refrigerators worldwide. Most of these are in industrialized countries, although their use in developing countries is rising steadily.^{22,24} Estimates suggest that domestic refrigeration represents around 6 percent of the total emissions of GHGs from refrigeration. Commercial, industrial and transport refrigeration accounts for the remaining 94 percent.²⁵

BOX 30

FINANCIAL AND ECONOMIC ASSESSMENT OF CLEAN-ENERGY TECHNOLOGIES IN THE MILK SUPPLY CHAIN

Milk spoils quickly if it is not chilled, yet many rural areas lack adequate cold storage facilities. Off-grid cooling technologies may help prevent milk losses without adding to GHG emissions. A recent FAO study analysed the financial and economic benefits of milk-cooling systems powered by biogas or solar energy in Kenya, Tunisiaⁱ and the United Republic of Tanzania.

In Kenya and the United Republic of Tanzania, the adoption of a biogas-powered domestic milk chiller requires an upfront investment of USD 1 600 but brings direct private benefits in the form of better quality milk and increased sales for farmers. Dairy farmers in Kenya and the United Republic of Tanzania can earn an additional USD 1.96 and USD 2.17 per day, respectively, by chilling the evening milk. At the same time, using a biogas milk chiller generates an additional annual value of USD 531 and USD 128 throughout the supply chain in Kenya and the United Republic of Tanzania, respectively. The introduction of chillers also creates jobs for skilled workers and improves health by reducing indoor air pollution from the use of conventional solid fuels, such as fuelwood and charcoal. In terms of environmental impacts, each chiller is estimated to make an annual reduction of

1.68 tonnes of CO₂ equivalent in GHG emissions by replacing solid biomass fuels. However, since the biogas used to run the milk cooler is produced by means of a digester, and each digester system requires between 50 and 100 litres of water per day to mix the manure, around 25 000 litres of additional water are required per year.

Solar coolers are an alternative to biogas-powered systems and are particularly suitable for sunny regions. In Kenya, for farmers who already have a system powered by a diesel generator, the solar cooler brings an additional USD 876 annually by cooling milk faster. In Tunisia and the United Republic of Tanzania, revenues increase by around USD 10 800 and USD 8 400, respectively.ⁱⁱ A solar cooler also brings economic benefits by generating employment and additional revenues throughout the supply chain in all three countries. By reducing milk loss, the technology also has the capacity of saving around 1 million litres and 3 million litres of water per year in the United Republic of Tanzania and Tunisia, respectively. However, this impact is negligible for Kenya.ⁱⁱⁱ Despite the overall environmental benefits, the required initial investment of USD 40 000 presents a substantial barrier to adoption.

ⁱ For Tunisia, only the solar cooler intervention is mentioned, since the biogas domestic milk chiller was not analysed in the country.

ⁱⁱ Unlike Kenya, no diesel-powered system or other cooling facilities are assumed as benchmark.

ⁱⁱⁱ The benchmark for Kenya uses similar amounts of water.

SOURCE: FAO, 2019²⁶

environmental impact often overlook the benefits that it brings in reducing food losses or waste.^{31–33} To evaluate the total environmental burden of food packaging adequately, the environmental footprint of the losses or waste that are avoided by using it, as well as the potential for recycling the packaging, must be considered. The net balance of environmental benefits and damage varies between food products. Using packaging to avoid losses of products with a heavy footprint in production may bring more environmental gains than not using packaging and facing a

higher level of losses.^{31, 32, 34} Avoiding the loss or waste of meat or dairy products – which have a large GHG footprint – by using packaging, for example, may result in a net cut in GHG emissions. **Box 31** discusses in greater detail the trade-off between the environmental footprint of food packaging on the one hand, and that of food losses or waste avoided on the other. Maximizing the environmental performance of packaging, for example by optimizing formats or using recyclable materials, is challenging but may bring considerable environmental benefits. ■

BOX 31

THE ENVIRONMENTAL PERFORMANCE OF PACKAGING TO REDUCE FOOD LOSS AND WASTE

Food packaging can help avoid food loss and waste and thus lessen the environmental burden; however, the production and disposal of packaging also harms the environment. The outcome of the trade-off depends on the environmental footprint of the food product (which varies across types of food and locations) as well as the packaging material used.³⁵ Glass, metal, plastic, paper, paperboard and biodegradable polymers each have their advantages and disadvantages.³⁶ The food-to-packaging ratio is defined as GHG emissions per kilogram of food produced and processed, divided by the GHG emissions associated with packaging 1 kg of that food. An extensive literature review found the range of the ratio to be from 0.06 to 700, depending on food and packaging configurations.³² Generally speaking,

the higher this ratio, the larger the benefits in terms of avoiding GHG emissions obtained by reducing losses through packaging. While the study only looked at the impact of the production and packaging of food on GHG emissions, it demonstrates how the resource intensity of food determines the environmental performance of its packaging.

A sensible and practical approach to the reduction of food loss and waste through packaging technologies considers the environmental footprints associated with different product categories. There are greater environmental benefits from reduced food loss and waste through packaging for categories of food with a high environmental footprint (e.g. meat and dairy products) than for those with a lower environmental footprint (e.g. vegetables and cereals).

CONCLUSIONS

Reducing food loss and waste can help meet the future demand for food from a growing and increasingly wealthy world population in a sustainable manner. Achieving sustainability requires more efficient natural resource use and reductions in the amount of GHGs emitted per unit of food consumed. Reducing food loss and waste can contribute towards this goal.

The linkages between food loss and waste and the sustainability of the food system are complex and context-dependent; they need to be well understood to formulate effective policies aimed at addressing environmental concerns through food loss or waste reduction. For example, improving the resource use efficiency of food at one stage in the supply chain may depress food prices and thus boost demand at subsequent stages; this can lead to an increase in overall resource use.

Food loss and waste reduction affects production and consumption decisions, and thus natural

resource use and GHG emissions, through changes in prices. How these changes are transmitted, both within the supply chain and across the wider economic system, determines their impact on the environmental footprints of food losses or waste.

Overall, the theory and case studies discussed in this chapter provide indications as to where to intervene to reduce food losses or waste, along the supply chain and geographically, depending on the environmental objective pursued. To address location-specific environmental stresses, interventions aimed at reducing losses should be implemented within the supply chain and geographically as close as possible to the location of the stresses. This will ensure that price signals are transmitted strongly to the actors causing the damage. Thus, interventions aimed at alleviating pressures on land or water resources should be undertaken at the primary production stage, where the bulk of the land and water footprint of the food system is concentrated. As GHG emissions accumulate when food products move along the supply chain, interventions to reduce the carbon footprint of food losses or waste

should therefore target stages towards the end of the chain. Since cuts in GHG emissions benefit the environment irrespective of where they occur, such interventions need not target a specific geographic location.

Other elements to be considered in formulating interventions are the potential to reduce food losses or waste at a particular location, the costs associated with particular interventions and their cost-effectiveness in comparison with alternative strategies. It is generally advisable to complement measures towards food loss and waste reduction with other types of interventions.

Policymakers must take due account of the fact that measures to reduce food losses or waste may also have some negative impacts on the environment. The use of packaging to protect and preserve food, for example, may lead to increased levels of plastic pollution. Similarly, refrigeration helps prevent food losses or waste but also causes GHG emissions.

Taking a longer-term view, reducing food loss and waste will always improve the efficiency of natural resource use and GHG emissions per unit of food consumed. The above considerations can provide initial guidance on where to focus efforts in reducing food loss and waste. However, the

lack of data on the costs and environmental benefits of measures towards food loss and waste reduction complicates any assessment of the efficiency and effectiveness of reducing food loss and waste as a means to improving environmental sustainability. Data gaps need to be overcome if reducing food loss and waste is to be widely adopted as part of a strategy for meeting the SDG targets relating to land, water and climate change.

Finally, although not the focus of this chapter, it is important to be aware that climate change may lead to greater levels of post-harvest losses, especially at the primary production stage.³⁷ Extreme weather events, such as droughts or floods, can destroy crops and livestock and damage infrastructure, while erratic rainfall may reduce harvests, impair drying processes and promote the development of moisture-reliant pathogens such as mycotoxins.^{38, 39} In addition, higher temperatures and greater humidity are likely to favour the spread of transboundary crop and animal pests and diseases. Temperature increases can also accelerate food spoilage, adding to concerns over food safety. An increase in climate-induced food losses may trigger an expansion in agricultural land at the expense of forests – which hampers GHG sequestration. ■

GUATEMALA

School Feeding being prepared by volunteer mothers who have been trained in nutrition, food handling and preparation, and good hygiene practices.

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CHAPTER 6

POLICYMAKING FOR FOOD LOSS AND WASTE REDUCTION – GUIDING PRINCIPLES

Key messages

1 Food loss and waste reduction can play an important role in achieving the SDGs, in particular those related to food security and nutrition and environmental sustainability. However, the linkages between food loss and waste reduction and these objectives are complex.

2 Public interventions – in terms of policies and infrastructure investments – may create an enabling environment that allows private actors to invest in the reduction of food losses or waste; such interventions should be chosen in line with policymakers' ultimate objective, whether related to economic efficiency, food security and nutrition, or environmental sustainability.

3 Greenhouse gas (GHG) emissions are a global problem and any intervention that reduces food losses or waste may help cut them, irrespective of location in the world; but interventions that target the final stages of the supply chain are likely to have the biggest impact.

4 Food loss or waste reduction measures are likely to be most effective at alleviating stresses on natural resources such as land or water if implemented near the location of these stresses, both geographically and along the supply chain.

5 To improve food security and nutrition, reduction interventions must target vulnerable populations. In countries where food insecurity is highest, policymakers should intervene early on in the supply chain, where food security impacts are likely to be strongest.

6 To ensure these reduction interventions are effective, current data collection methods need significant improvement to allow monitoring and impact assessments. Countries should share practical experiences, for example as to the identification of critical loss points as well as the costs of monitoring efforts.

POLICYMAKING FOR FOOD LOSS AND WASTE REDUCTION – GUIDING PRINCIPLES

Earlier chapters of this report discussed the motives of private actors for investing in food loss or waste reduction (the business case), as well as the rationale for public intervention. The argument has been made that public interventions may be justified by the economy-wide efficiency gains to be had from loss or waste reduction (the economic case), as well as its potential contribution to improved food security and nutrition or environmental sustainability. This chapter discusses the types of public interventions that can reduce food losses or waste, not as a goal in themselves but rather as a means towards wider social or environmental goals. The scarcity of reliable data as to how much and where food is lost or wasted, and the lack of information regarding the costs of reduction efforts, are a major obstacle to the formulation of effective policies for loss or waste reduction. The chapter therefore also presents a possible road map for the collection of reliable, comparable data worldwide. ■

ENABLING PRIVATE ACTORS TO REDUCE FOOD LOSS AND WASTE

Actors in the food supply chain are primarily driven by self-interest: producers aim to maximize profits and consumers their well-being. As rational decision makers, they reduce food losses or waste as long as the benefits outweigh the costs. Completely eliminating all food loss and waste is unrealistic, as the costs would be exorbitant.¹

Chapter 3 has argued there may be a business case for private actors to reduce food losses or waste.² While driven by financial motivations, this may also contribute to wider societal goals:

improved productivity, job creation, and better food security and nutrition and/or environmental sustainability. Innovative loss-reducing technologies, for example, can significantly improve the efficiency of production, as well as environmental sustainability.

Conversely, there are also situations where the business case for reducing food loss and waste may be weak, i.e. where suppliers and consumers face constraints when deciding on levels of food loss or waste that they consider optimal.^{3,4} For example, though smallholders may benefit from reductions in post-harvest losses, they often lack the necessary funds to bring about such reductions.⁵ Other prominent barriers include lack of information, distance to markets, access to social capital, weak tenure security and exposure to risks and shocks.⁴ These barriers are often more severe for women than for men. Moreover, even if private stakeholders, driven by private profit motives, implement solutions that indeed result in food loss and waste reduction, the impact on levels of food loss and waste is likely to be limited.

Given the potential for food loss and waste reduction to boost economic growth and create jobs, there may be a justification for public interventions to eliminate these barriers and encourage actors to further reduce losses or waste. For example, providing consumers and suppliers with information on options to reduce food losses or waste has proven to be a cost-effective strategy for policymakers (see [Boxes 18](#) and [32](#)).

Public interventions that affect food prices can also influence incentives for consumers and producers to avoid food losses or waste, since the higher the price of food, the greater the financial incentive for suppliers or consumers to avoid losses or waste. On the other hand, policy

BOX 32 FOOD WASTE REDUCTION CAMPAIGNS – CHINA, TURKEY, NORTH MACEDONIA AND DENMARK

An NGO in China launched the Clean Your Plate campaign in 2013 to raise consumer awareness about food waste. More than 750 restaurants in Beijing participate in the campaign, which has also received considerable public support. Restaurants serve smaller dishes, encourage the use of doggy bags or offer discounts and certificates to customers who do not leave any food on their plate.⁸ The following year, the Chinese Government took several steps towards food loss and waste reduction, issuing a circular on “Practising strict economy and fighting against waste”. Evidence of the impact is unclear.

Turkey launched a campaign to reduce bread waste in 2013 to raise public awareness about waste, avoid losses throughout the supply chain and promote consumption of whole wheat bread. Despite the fact that any efforts in the campaign are voluntary, it has resulted in fewer loaves being wasted daily, down from 5.9 million in 2012 to 4.9 million in 2013. By encouraging consumers to purchase only the bread they can actually eat, the campaign resulted in a drop in bread purchases of 10 percent and consumers saved a total of USD 1.1 billion in 2013.^{9, 10}

Since 2017, a North Macedonian civic-led network set up in 2011 to reduce national organic and non-organic waste, has focused on food waste.¹¹ Initiatives include a web platform that allows businesses from farmers to food service providers to post food donations online and civil society organizations to claim these donations for redistribution. The

organization further advocates legislative changes on broadening food surplus donation regulations, including tax benefits for food donors.¹² Another initiative is a pilot learning programme about food waste targeting secondary school students, the Food Waste Experiential Program.¹³

Denmark provides an interesting example of the impact that awareness raising can have on food loss and waste. The country reduced food waste by 25 percent between 2010 and 2015 through a number of initiatives, including educating consumers and supermarkets offering discounts on food near its expiration date or with superficial flaws.¹⁴ Leading this movement is the Stop Wasting Food campaign, supported by both the private and the public sector.^{14, 15} As part of the initiative, consumers received tips on how to best plan food purchasing and prepare meals. It also stimulated innovation among food manufacturers and retailers, for example in packaging design and portion sizing. Because they wasted less food, consumers saved money and a number of price-related initiatives meant that food prices decreased too.^{16, 17} Local authorities responsible for waste disposal benefited from lower waste disposal costs: primarily incineration, as most food waste in Denmark is incinerated.¹⁵ Besides improving their reputation for social and environmental stewardship, participating businesses also increased sales – through being able to sell products that would otherwise be thrown away – and decreased their costs (e.g. disposal).¹⁷

interventions in agriculture or food that keep food prices artificially low (e.g. through food subsidies) may have the unintended consequence of encouraging food loss or waste (see [Box 33](#)).

Public policies to promote overall economic development can have the side benefit of promoting food loss and waste reductions by the private sector. For instance, inclusive financial

services, such as credit and insurance, may allow suppliers to invest in technologies that also reduce food loss and waste. An example of an economic development intervention with a side benefit of reducing food losses is the International Bank for Reconstruction and Development’s financing of improved grain storage in Mexico, boosting smallholders’ competitiveness.⁶

BOX 33 REFORMING BREAD SUBSIDIES IN THE NEAR EAST

While food subsidies may be an element in social safety nets and increase food security, they can also induce consumers to waste more food.¹⁸ Depending on their design, the benefits may be largely captured by high-income consumers, without necessarily helping the poor.¹⁹

Before its reform in 2014, the bread subsidy system in Egypt was believed to encourage consumers to waste bread and suppliers to behave opportunistically.⁹ Subsidized flour was often bought at low cost and resold at higher prices, either as flour or bread, or leaked from the supply chain. This leakage occurred at all stages of the supply chain, in warehouses, mills and bakeries. The 2014 reform introduced a smart card system that subsidizes bread rather than flour and limits the number of loaves a person can buy each day. Unused credit can be used to buy other subsidized food items. Thus, consumers – and through them, suppliers – have an incentive to manage their bread purchases more efficiently.^{9, 20, 21} After the reform there was a

decrease of 15–20 percent in the demand for bread, as consumers started to adjust their consumption.⁹

Other countries in the region, such as Jordan, have adopted a similar approach. There bread subsidies are seen as a way to improve food security and thus ensure stability, especially after the bread riots of 1996. However, it is estimated that the needy consume only 13 percent of subsidized bread, while 12 percent is consumed by wealthy segments of society.²² Low-priced subsidized wheat flour is often resold by bakers or used to produce non-subsidized bread; livestock owners even use it as animal feed.^{22, 23} To reduce public spending and avoid food wastage, in 2018 the government replaced its broad bread subsidy programme with a targeted assistance system that sets new price caps for bread without directly subsidizing bakeries.^{23, 24} Beneficiaries are paid through an electronic benefit transfer card to counter fraud and waste. The new system is expected to reduce government spending by around USD 106 million.²³

Another strategy to promote such reductions is through public–private partnerships. Coordinating public and private investment in infrastructure and logistics (for example, through World Bank Sustainable Development Bonds) may improve producers' access to markets, thus reducing losses.⁵ International trade cooperation or free trade agreements that reduce delays in moving perishable food products across borders can also help avoid losses.

One important aspect that public intervention must take into consideration is that food loss and waste reductions have winners and losers. The benefits (or costs) are not always enjoyed (or borne) by those implementing them.¹ For

instance, a reduction in food losses by processors may reduce demand from processors for farmers' output, thus depressing farmers' income. The distribution of the costs and benefits along and beyond the food supply chain is of major importance when formulating policies to reduce food loss and waste.

Apart from the financial gains, private initiatives to reduce food loss and waste may also bring considerable benefits to wider society in terms of food security and nutrition (see Chapter 4) and environmental sustainability (see Chapter 5). The precise linkages between food loss and waste reduction and these societal objectives are not always straightforward and are discussed in the following section. ■

⁵ World Bank Sustainable Development Bonds allow investors to help borrowing member countries achieve their development goals through financial services, access to experts and a pool of knowledge in development-related disciplines.⁷

PUBLIC INTERVENTIONS FOR BETTER FOOD SECURITY AND NUTRITION AND ENVIRONMENTAL SUSTAINABILITY

The previous section focused on the role of public interventions in facilitating the business case of reducing food loss and waste, which may contribute to economic growth and job creation, thus benefiting not only private actors but also society at large. Aside from objectives linked to such financial gains by producers or consumers, the report has focused on two key objectives associated with the reduction of food loss and waste: food security and nutrition (see Chapter 4) and environmental sustainability (see Chapter 5). Public interventions that aim to produce these societal gains through food loss and waste reduction can do so by, for example, reducing market failures and missing markets, as well as the negative externalities caused by private actors.

As discussed in Chapters 4 and 5, the impacts of loss or waste reductions on food security and nutrition and environmental sustainability depend *inter alia* on the location of the reductions, both geographically and in the food supply chain.

- Loss or waste reductions are expected to have a greater impact on food security if they focus on the earlier supply chain stages, by boosting supplies and reducing food prices throughout the supply chain, to the particular benefit of the most vulnerable populations.
- Interventions towards loss or waste reductions may aim to improve the environmental sustainability of the food system by, for example, reducing pressures on land or water resources, or lowering GHG emissions. This is achieved by intervening after the environmental damage has occurred. This is particularly important for cutting GHG emissions, which accumulate as a food product moves along the supply chain.

Policy decisions related to food loss or waste reduction also depend on where in the food supply chain most food is lost or wasted. Indeed, there is little point in focusing on locations where the levels are low. However, targeting the locations in the food supply chain where losses or waste are highest is not necessarily the most effective strategy in achieving societal objectives. For example, policies aimed at improving environmental sustainability should also take into account where in the food supply chain environmental impacts of food loss and waste are largest.

Low-income countries with high food insecurity may focus on working to improve food security and nutrition; at the same time, ensuring sustainable use of land and water resources may also have a strong positive impact on food security and nutrition. Countries with such characteristics tend to intervene early on in the supply chain and often at the primary production stage, where food security impacts are likely to be strongest and losses highest.

High-income countries – where food insecurity is generally low, and nutrition better – are likely to focus on environmental objectives and especially cutting GHG emissions. Reducing food loss or waste is more effective in cutting these emissions at the later stages of the supply chain and particularly the retail and consumption stages. Here, the GHG emissions embedded in food products are highest; in addition, in high-income countries, most food wastage occurs at these stages.

There may also be synergies between objectives; reduced on-farm losses in low-income countries, for example, may lessen stresses on natural resources, while at the same time improving food security. There may also be synergies with broader development objectives, including an enabling business environment. Indeed, investments aimed at broader agricultural development – for example, to improve infrastructure or storage facilities, enhance rural finance services or boost market opportunities – may also reduce losses or waste as a side effect.

Note that there may be trade-offs between objectives, as an intervention may contribute

towards one objective but worsen outcomes in another. Improving access to diversified and nutritious diets, for example, entails a certain level of food loss or waste and possibly of food products with a high environmental footprint.²⁵ Another example of the trade-off between objectives is boosting cold chain capacities, which may improve food security and nutrition but also result in greater GHG emissions. Sustainable cooling solutions that use renewable energy resources present a good solution to prevent food spoiling without adding to GHG emissions. Local off-grid or microgrid-based solutions are an attractive option, since installation costs are now comparable to, or even lower than, connecting to electricity grids (see Box 30 for a feasibility analysis of off-grid cooling technologies in Kenya, Tunisia and the United Republic of Tanzania).²⁶ Other small-scale, simple, self-build cooling solutions may offer an affordable and more sustainable alternative to conventional cold rooms. An example is Coolbot, a device that converts a standard window air conditioner unit to a walk-in refrigerator cooler unit; it can also be powered by an off-grid system (using solar power, for example). It is estimated to be about 25 percent more efficient than conventional cooling systems. A study in Kenya found Coolbot prolonged the shelf life of mangoes by up to 23 days compared to ambient storage conditions.²⁷ ■

PUBLIC INTERVENTIONS IN PRACTICE – LINKING POLICY OBJECTIVE AND ENTRY POINT ALONG THE FOOD SUPPLY CHAIN

This section elaborates on the synergies and trade-offs between food loss and waste measures aimed at promoting food security and nutrition on the one hand and improving environmental sustainability on the other. It also discusses policies to encourage the private sector to invest in food loss and waste reduction.

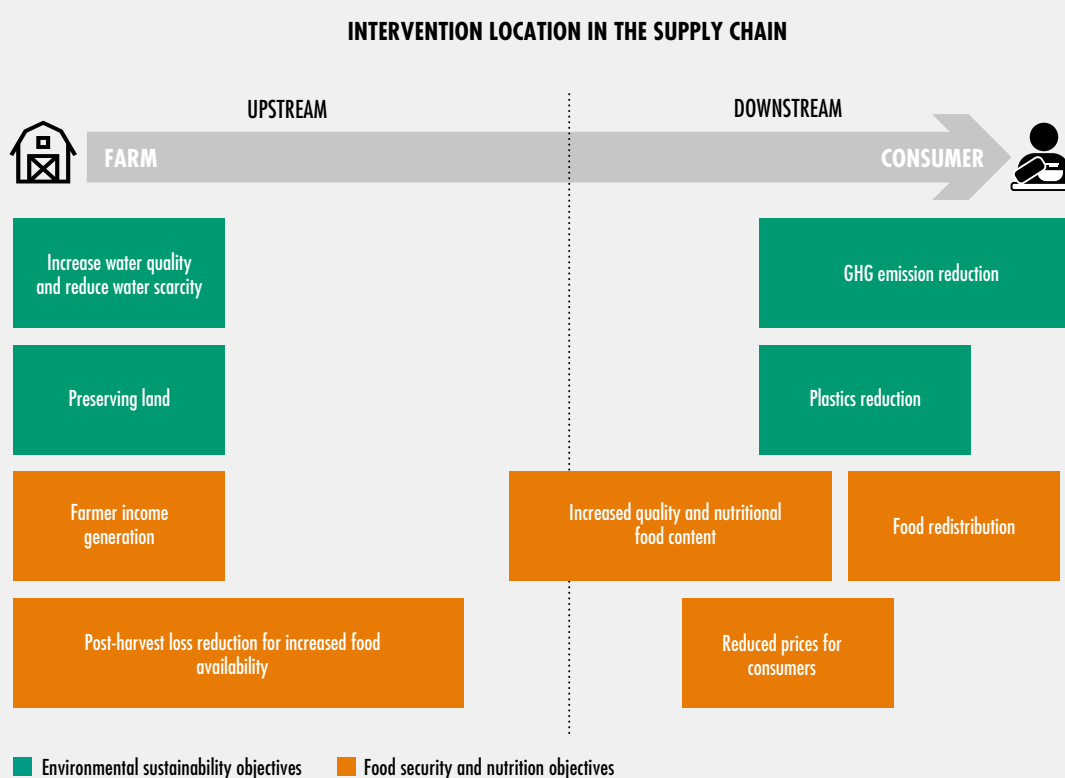
Figure 17 illustrates the linkages between various objectives of food loss and waste reduction interventions and their entry points in the supply chain. This figure can help policymakers narrow down the area for intervention based on the objective so that they focus efforts (e.g. information gathering) on those interventions that are most likely to contribute to that objective.

The colour of the boxes indicates whether an objective is related to food security and nutrition (orange) or the environment (green), while the positioning indicates the best entry point along the supply chain for measures aimed at the objective. For example, interventions to boost farmers' incomes may focus on on-farm loss reduction, while GHG emissions are best addressed by focusing on consumer waste. Certain objectives can only be addressed in the later stages of the supply chain because they concern either the final product or the packaging of that product.

Figure 17 does not distinguish between objectives that are global and those restricted to a local area. However, a number of basic conclusions in this respect can be drawn from Chapters 4 and 5:

- ▶ If the objective is to lower GHG emissions, then the geographic location of reduction interventions does not matter; reducing GHG emissions by 1 tonne of CO₂ will have the same global impact irrespective of where it occurs.
- ▶ Interventions aimed at improving food security and nutrition should be implemented at the local level, as those in one part of the world are unlikely to affect food security and nutrition thousands of kilometres away.
- ▶ At the local level, synergies exist between the objectives of improving access to food and reducing environmental footprints through interventions earlier in the supply chain. However, reducing food losses is unlikely to be the most effective way to tackle local environmental problems as a primary objective. These are best addressed by directly improving resource use efficiency.

FIGURE 17
OBJECTIVES OF LOSS AND WASTE REDUCTION MEASURES AND THEIR ENTRY POINTS ALONG THE FOOD SUPPLY CHAIN



SOURCE: FAO

Table 2 shows a number of examples of interventions towards food loss or waste reduction around the world. They include both public interventions – aimed at improving food security and nutrition or environmental sustainability, or creating an enabling environment to allow private actors to reduce losses or waste – and measures implemented by private actors. Interventions may have more than one objective and may also bring side benefits. Improving “best before” and “use by” labelling may enable retailers to sell food that would otherwise be wasted. It may also help consumers diversify their diets, thus contributing to better nutrition. ■

ENSURING COHERENT POLICIES FOR FOOD LOSS AND WASTE REDUCTION

Food loss and waste reduction should be seen not only as a goal in its own right but also as a means to achieve other objectives, such as food nutrition and security and environmental sustainability. Policies aimed at promoting broad agricultural or economic development may enable suppliers along the food supply chain to make investments that reduce food losses or waste as a side benefit. »

TABLE 2
EXAMPLES OF INTERVENTIONS TOWARDS FOOD LOSS AND WASTE REDUCTION AROUND THE WORLD

	Objective(s)	Co-benefit(s)	Scope	Food supply chain stage
Improving storage to reduce on-farm losses and boost farmers' incomes Adequate storage conditions give stability to smallholders by preventing post-harvest losses and allowing them to sell their produce later in the season at favourable prices. A cost-benefit analysis for the maize, bean and cowpea supply chains in Benin and Mozambique found the investment in hermetic bags and metal silos to be beneficial for farmers. Results suggest that farmers in both countries may realize an up to 11-fold return on investment. The return will largely depend on whether farmers sell their crops immediately after harvest or during the lean season, on the prices paid for stored crops later in the season, and on the level of post-harvest losses avoided in a given context. One limitation of the analysis is that it assumes that metal silos and hermetic bags are 100 percent effective in preserving the produce until the lean season (i.e. eight months later), which may not be the case in practice. The initial investment costs also present a significant barrier to adoption, especially for the metal silo, and it can take farmers up to seven years to pay back the cost of the investment. Public policies should promote inclusive financial services, such as credit or lower import taxes, so that modern technologies are accessible to farmers. ^{28, 29}				
Improving fish smoking and drying practices to prevent losses Smoking and drying fish are the most common small- and medium-scale processing methods. Their use has a great impact on the level of post-harvest losses, the environmental footprint of the fish sector and consumer health. FAO has pioneered an innovative technique to smoke and dry fish, the FAO-Thiaroye Technique, which has greatly improved smoking and drying practices. The FAO-Thiaroye Technique can be used regardless of climatic conditions and increases the range of species that can be processed, which strengthens fish processors' resilience in the face of climatic variability. The technique has resulted in a near complete elimination of losses at the processing stage and enhances the quality and safety of the finished product. In Côte d'Ivoire, the technique is estimated to reduce losses of smoked fish rejected on food safety or quality grounds to the tune of USD 1.7 million annually. ³⁰	 			
Climate-friendly cold storage In Morocco, FAO and the European Bank for Reconstruction and Development (EBRD) assessed the potential for more efficient climate control techniques, including cold storage. Improving the efficiency of the cold chain was found to be a low-hanging fruit, offering the greatest potential to reduce GHG emissions and improve resource use efficiency of all the 12 technologies and practices reviewed. However, limited access to capital, uncertainty as to the financial return on investments and regulatory issues constitute barriers to adopting efficient cold storage technologies. The Finance and Technology Transfer Centre for Climate Change (funded by the EBRD and the Global Environment Facility) helps businesses adopt green cooling technologies and overcome problems related to malfunctioning markets for climate technology, largely through grants and technical support. ³¹				
Extending shelf life without plastics or cold storage Apeel is an innovative natural technique to coat fresh fruits and vegetables with a thin peel of edible plant material that slows down water loss and oxidation – the factors that cause spoilage. ³² The start-up that developed the technique was launched in 2012 in the United States of America. ³³ It claims Apeel extends the lifespan of avocados by almost a week and doubles their ripeness window from two to four days by reducing water loss by 30 percent and slowing down softening by 60 percent, relative to untreated avocados. The developers also claim that their technique results in a fivefold reduction in mechanical damage. ³⁴	  			

TABLE 2
(CONTINUED)

	Objective(s)	Co-benefit(s)	Scope	Food supply chain stage
Discounting ageing produce Wasteless, an innovative pricing technology using machine-learning, helps retailers cut waste and increase their revenues through dynamic pricing. The technology ensures that electronic shelf labels automatically discount the prices of food products as their expiration date comes near. Wasteless allows for a continuous inventory of products according to their expiration dates and connects to stores' point-of-sales systems. A pilot at a leading Spanish retailer resulted in an average decrease of 32.7 percent in overall waste and an average revenue boost of 6.3 percent. Two-thirds of consumers faced with choosing between a discounted product with a shorter expiration date and the same product with a longer expiration date sold at its full price chose the discounted product. ³⁵	■	■	◎	↓
Innovative solutions for food redistribution in the European Union In recent years, EU countries have been applying solutions to encourage food operators to donate their surplus food. For example, in 2016, a law was passed in Italy to relax regulations that made donations for food redistribution cumbersome. The law allows food to be donated even if it is past its "best before" date or is mislabelled (as long as it does not pose any risks in terms of food safety), and allows farmers to donate unsold produce to charities without incurring costs. ³⁶ Belgium and France provide other examples of how the administrative requirements of donating food can be simplified and donation by businesses encouraged. ¹²	■		□	↑ ↓
National strategies for food loss and waste reduction and prevention in Chile and Argentina In Latin America, several countries have adopted policies to stem food loss and waste. In 2017, for example, Chile established the National Committee for Food Loss and Waste Prevention and Reduction, to facilitate and coordinate strategies to prevent and reduce food loss and waste. Formed by public institutions and private organizations, the Committee's 2018–2019 action plan focuses on three pillars: (i) governance; (ii) information and communication; and (iii) research, technology and knowledge required to reduce food loss and waste. ³⁷ Similarly, Argentina created a National Programme for the Reduction of Food Loss and Waste in 2015; more than 80 public and private institutions have since joined to form the National Network for the Reduction of Food Loss and Waste. As part of the programme, a national campaign named "Valoremos los Alimentos" was launched, providing information and videos on how to prevent food loss and waste. ³⁸	■		□	↑ ↓
OBJECTIVE	SCOPE			FOOD SUPPLY CHAIN STAGE
■ Food security and nutrition objective	◎ Location-specific	↑ Upstream		
■ Environmental objective	□ National or regional	Midstream		
■ Business-enabling objective	○ Global	↓ Downstream		

» However, food loss or waste reductions do not guarantee improved food security and nutrition *and* environmental sustainability. Measures may contribute towards one objective but lead to a deterioration in another, depending on the location of the supply chain reduction. It is therefore of crucial importance to ensure policy coherence by considering the potential and actual impacts of all reduction options.

Certain public interventions, especially those aimed at improving food utilization and stability, may lead to increased food losses or waste. Efforts to ensure access to nutritious diets for all, for example, may result in such a rise, as the share of highly perishable products in these diets is high. Efforts to reduce food losses or waste should not compromise food security and nutrition. Note that as their incomes rise, consumers may actually waste increasing amounts of food.

BOX 34

REGIONAL STRATEGIC FRAMEWORKS TO TACKLE FOOD LOSS AND WASTE EFFECTIVELY

Regional and national platforms between governmental and non-governmental actors in Africa, Latin America and the Caribbean contain food loss and waste reduction goals in their strategic frameworks.

The Inter-American Development Bank has created #SinDesperdicio, a platform aimed at promoting innovation and improving the quality of public interventions on food loss and waste reduction in Latin America and the Caribbean. Actors including FAO, the Consumer Goods Forum, the Global FoodBanking Network, IBM and other companies participate in the platform.

The African Union has developed a regional strategy to reduce post-harvest losses with the support of FAO. The regional strategy helps countries in the African Union achieve the goal of the Malabo Declaration of halving post-harvest losses by 2025 (see Box 22) by aligning national strategies as much as possible. The strategy targets interventions at selected stages of the supply chains of particular food products. Data collection focuses on the indicator for post-harvest losses agreed by member countries and on monitoring and evaluation.

The alignment of strategies can ensure resources are used in the most efficient way possible, both in collecting data and carrying out the actual interventions. Boxes 34 and 35 provide examples of regional strategies for food loss and waste reduction in Latin America and the Caribbean and Africa, and the EU, respectively.

To achieve long-lasting food loss and waste reduction results, policy interventions must be designed and implemented in a way that accounts for gender. To ensure this happens, policymakers should:

- ▶ consider the results and recommendations of gender-sensitive maps and analyses of food supply chains;
- ▶ identify the gender constraints that actors face at critical loss points in the food supply chain;
- ▶ duly consider the differences in needs, constraints and preferences between women and men active in the food supply chain; and
- ▶ assess the gender and social implications of any proposed solutions.

Questions to consider in gender-responsive planning include:

- ▶ Do the suggested solutions exacerbate gender inequalities?

- ▶ Are they appropriate in the cultural and social context of the supply chain and can they be adopted widely to have a long-term impact on losses or waste?⁴⁷

Finally, it is imperative to assess accurately whether reduction interventions achieve their objectives. This calls for the exact measurement of the problem targeted, as well as precise monitoring and evaluation of the interventions – all of which requires reliable data on the level of food losses and waste. The current lack of solid data constitutes a serious barrier to successful policymaking. The following section lays out a road map for improved data collection on food loss and waste. ■

TOWARDS BETTER DATA ON FOOD LOSS AND WASTE – A ROAD MAP

Obtaining reliable information on the amount of loss and waste for a wide range of commodities along the whole food supply chain is challenging. Although food loss and waste research has been ongoing for the past 40 years, there are still no internationally used standards, concepts or definitions of food loss and waste; current

BOX 35 REDUCING FOOD LOSS AND WASTE IN THE EUROPEAN UNION

The EU is committed to the global fight against food loss and waste. Food waste prevention was singled out as a priority area in the EU Circular Economy Action Plan, adopted in 2015.^{39, 40} This called on the European Commission to establish a multi-stakeholder platform dedicated to food waste prevention.ⁱ The EU Platform on Food Losses and Food Waste, established in 2016, brings together all key actors representing both public and private interests from farm to fork to advance EU progress towards SDG Target 12.3. Members include international organizations (FAO, UN Environment, the Organisation for Economic Co-operation and Development), EU institutions, experts from EU Member States, and stakeholders from the food supply chain, including food banks and other NGOs.⁴¹

The Platform aims to support all actors in defining measures to prevent food waste, including possible recommendations for EU-level action, sharing best practices and evaluating progress. With the support of the EU Platform on Food Losses and Food Waste, the European Commission has adopted EU guidelines to facilitate food donations and the redirection of food no longer fit for human consumption into feed. It has developed a food waste measurement methodology and is working to improve date labelling practices.^{42, 43}

Measurement is critical to food waste prevention. Revised EU waste legislation adopted in May 2018

has introduced specific measures which will provide the EU with new and consistent data on food waste levels.⁴⁴ On 3 May 2019 the European Commission adopted a Delegated Act laying down a common food waste measurement methodology to help Member States quantify food waste at each stage of the food supply chain. Based on a common definition, the methodology will ensure coherent monitoring of food waste levels across the EU. The Delegated Act is expected to come into force in autumn 2019.⁴⁵

EU Member States are expected to provide data separately for five stages of the food supply chain: primary production, processing and manufacturing, retail and other distribution of food, restaurants and food services, and households. This covers the scope of both sub-indicators proposed to measure progress towards SDG Target 12.3 – the FLI and the FWI. The collected data will contribute in a significant way to reporting for both indices.

The European Commission's Reflection paper, *"Towards a sustainable Europe by 2030"*, highlights the importance of pursuing the EU Action Plan to fight food waste to strengthen the sustainability of our food systems.⁴⁶ The forthcoming "Recommendations for action in food waste prevention", to be adopted by the EU Platform on Food Losses and Food Waste by the end of 2019, are expected to make an important contribution to this redesign of EU food systems.

ⁱ EU legislation does not use the concept of food loss and its definition of food waste covers the whole food supply chain.

measurement methods have not proved effective in generating data;⁴⁸ and properly conducted surveys tend to be costly and time-consuming. Given these obstacles, very few countries have measured their full loss and waste accurately along the food supply chain.

However, progress is being made. As of now, FAO is producing model-based estimates of food losses as a short-term benchmark in the absence of nationally collected food loss data. These are used in Chapters 1 and 2. In the long

run, though, the strategy is to replace modelled estimates with data using the guidelines and methodology developed for the Food Loss Index (FLI). Activities are organized around: (i) a methodological agenda; (ii) a capacity development agenda; (iii) a data collection agenda; and (iv) advocacy and partnerships. More details are provided in [Box 36](#).

It is widely assumed that food waste is not a major problem in the developing world, when in fact data are entirely absent and the problem »

BOX 36 A ROAD MAP FOR IMPROVED DATA COLLECTION ON FOOD LOSSES

The methodological agenda – international concepts and definitions and a standardized approach to estimating food loss

A consensus on a precise definition of food loss and waste does not exist and the concepts of loss and waste are often used interchangeably. As a result, data across countries are hardly comparable. FAO has worked to consolidate definitions, both with external partners and through internal consultations, and has agreed on definitions of food loss and waste from several perspectives. A detailed description of concepts related to food loss and waste can be found in Chapter 1 of this report (see Boxes 1 and 2).

Measuring food loss is not an easy task, given the multidimensional nature of losses, the different product characteristics, the variety of supply chains and types of actors (from small household farms to large commercial holdings), the various supply chain stages where losses occur and need to be measured, and the difficulty of objective measurements. To this end, in 2018 FAO and the Global Strategy to Improve Agricultural and Rural Statistics developed “*Guidelines on the measurement of harvest and post-harvest losses*”, covering the production (harvest), post-harvest and processing stages in the food supply chain.⁴⁹ The Guidelines offer cost-effective statistical methods and are targeted primarily, but not exclusively, towards developing countries. Those for grains are being tested in three countries of sub-Saharan Africa. Three additional guideline documents, covering loss measurement of fruits and vegetables, animal products and fish products, have also been developed.⁵⁰ The Guidelines are complemented by field test reports providing practical experience and solutions for specific contexts.

Using comparable methods within and across countries will help improve the modelled estimates and enhance understanding of the levels and causes of losses; this will lead to more informed decisions on how to tackle the problem.

A capacity development agenda – supporting countries in collecting food loss data

As a starting point, a set of resources is being made available online, including the Guidelines, the reports from the field tests, eLearning courses (on the FLI and the Guidelines for data collection), standard questionnaires and training material. These resources are complemented by a round of international training workshops in all regions to transfer knowledge and help countries tackle the measurement issue in all its complexity. The next steps will be to plan support in collecting data through new or existing initiatives in a set of priority countries. These will be grounded in national statistical systems to ensure sustainability of data collection and to strengthen the capacity of the systems themselves. Additional tools will be available, including guidance for post-harvest loss surveys, building on the Census of Agriculture framework – designed to provide support and guidance for countries to carry out national agricultural censuses – or adding a sub-survey on farm losses in the Agricultural Integrated Survey (AGRIS), a farm-based, multi-year survey programme proposed by FAO to improve agricultural and rural statistics.^{51, 52} The tools will cover sample design issues and the questionnaires or questions to be used or added to existing surveys.

In the short term – and in the absence of data – modelled estimates will be used within the framework of Food Balance Sheets (FBS). Since estimating losses with econometric modelling can help reduce data collection costs and increase the quality of data, FAO has developed a loss imputation model which countries may choose to adopt and adjust to generate improved data on food loss.^{49, 50}

A data collection agenda – mining existing information to estimate food losses

In parallel with the capacity development agenda, as custodian agency of the FLI, FAO regularly collects available loss data from all countries, along with its annual Agricultural Production Questionnaire.

BOX 36
(CONTINUED)

Data collection started in 2016 and has been strengthened in 2019: a separate questionnaire on food losses went out in spring 2019 to all countries to gather all existing data for the past decade and validate the historical data collected so far by FAO for its Supply Utilization Accounts. Later on, a separate questionnaire will be merged with the annual Agricultural Production Questionnaire to ease the burden for respondents.

The data thus obtained will be used to compile the FLI, where possible, and to improve the model-based estimates.

Engaging countries in measuring food waste in retail, food services and households

Despite FAO's efforts, no single institution can tackle food loss and waste alone or unilaterally address the many dimensions of food loss and waste at the local and global level. Partnerships to align and join efforts with technical and political stakeholders, private and public entities, both nationally and internationally, will be critical. Such partnerships should ensure a consistent and integrated food systems approach to policy formulation, technical support and measurement of food losses and waste.

» may be much greater than anticipated, especially in emerging economies. UN Environment is adopting a two-tier approach in developing the FWI to measure and monitor food waste worldwide. A draft methodology has been developed, with a first tier building upon the *Food Loss and Waste Accounting and Reporting Standard* (FLW Standard) published in June 2016. Given the lack of national data on food waste (it is estimated that currently data are available for only 10 percent of the world's population), UN Environment is developing a second-tier method involving a model that will provide food waste estimates for all countries. The precise road map for data collection on food waste will depend on the final design of the FWI under development.

To achieve SDG Target 12.3, efforts by FAO and UN Environment to develop the FLI and FWI, respectively, will need to be supplemented by much government action at the country or even subnational level. Designing interventions for action requires ex-ante assessment of potential interventions such as those suggested in this report or ex-post assessment of interventions already in place; these assessments require measurement in the first place. Indeed, a number of countries have already taken steps to start or improve the measurement of their losses

and waste (see, for example, Boxes 34 and 35). However, commitments are often collective expressions of intent that still need to be translated into action so that reductions can be monitored.

The private sector also has a central role to play when it comes to measuring losses or waste. Business-level data are valuable for tracking industry progress over time, identifying critical loss points within businesses, filling data gaps in national surveys, sharing best practices, further motivating other companies to reduce their losses or waste, and prompting interventions and policy analysis. Even though businesses have been making progress in measuring and reducing food loss and waste over the past few years (see Box 15), the private sector will need to step up if the scale of reductions called for by SDG Target 12.3 is to be achieved. Only when countries and businesses start to establish more solid baselines, develop credible means of monitoring and measuring food loss and waste, and make their results publicly available and easily accessible, will an assessment of national and global progress towards SDG Target 12.3 be possible. ■

CONCLUSIONS

This report has discussed the role that food loss and waste reduction can play in achieving the targets of the SDGs – not only SDG Target 12.3, which explicitly calls for a reduction in food losses and waste, but other targets, too (see [Figure 1](#)). Private stakeholders may have a financial incentive to invest in the reduction of food losses or waste and their efforts may have positive impacts on the wider societal goals of food security and nutrition and environmental sustainability, the focus of this report. Public interventions may provide incentives to private actors to reduce food losses or waste and help them overcome constraints.

This report has argued that public interventions aimed at broad economic development may have the side effect of leading to reduced food losses or waste. Public interventions on food loss or waste reduction must be formulated in line with policymakers' ultimate objective of increasing economic efficiency, improving food security or nutrition, or ensuring environmental sustainability.

Low-income countries with high levels of food insecurity may choose to focus on improving food security and nutrition. Interventions focusing on losses early on in the supply chain – and especially on-farm losses – are likely to have the strongest impact.

High-income countries – where food insecurity is generally low, and nutrition better – are likely to focus on environmental objectives, especially reduced GHG emissions. Efforts towards food loss or waste reduction are more effective at reducing these emissions if implemented at the

later stages of the supply chain, particularly at the retail and consumption stages, where the GHG emissions embedded in food products are highest.

GHG emissions have a global impact, irrespective of where they occur. The geographic location of interventions to reduce GHG emissions through food loss or waste reduction is therefore irrelevant. Food loss or waste reduction measures are likely to be most effective in alleviating stresses on natural resources (such as land or water) if implemented near the location of these stresses, both geographically and along the supply chain. Note that measures aimed directly at better efficiency in the use of natural resources or reducing environmental stresses are often more effective in this regard than food loss or waste reduction.

Any reductions in the amount of food wasted by consumers in high-income countries are unlikely to have a more than negligible effect on the food security status of vulnerable groups in distant low-income countries.

The formulation of effective policies towards food loss and waste reduction requires comprehensive information as to how much and where – both geographically and along the supply chain – various food products are lost or wasted. The current lack of comparable and reliable information constitutes a major obstacle to the development of effectively targeted policies to reduce food losses or waste. Improving statistics on food loss and waste is therefore a priority area for FAO – as it should be for the international community and national governments, particularly in monitoring progress towards achieving the SDGs. ■

TECHNICAL ANNEX

FOOD LOSS INDEX METHODOLOGY

The loss estimates used in this report are based on the methodology developed by FAO to monitor food losses within SDG Target 12.3 – “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”. Under this target, FAO developed a Food Loss Index (FLI) monitoring food losses on a global level for a basket of key commodities covering crops, livestock and fisheries products from harvest up until retail. The index focuses on the supply stages of food chains and measures changes in percentage losses over time measured by the Food Loss Percentage (FLP).

The FLI is expressed in a base 100 and allows for looking at positive and negative trends in FLP compared to the base period of 2015 and for assessing countries’ progress in reducing losses. The index is comprised of annual FLP data, which are interpreted as the percentage of production that does not reach the retail stage. The FLP is a relative measure of a country’s food system efficiency compared to other countries. The FLP can be disaggregated into loss percentages by commodity and food supply chain stage (where stage level information exists). The overarching objective is that countries will want to make reductions overall at the national level, while developing policies and tracking progress in finer detail. FAO, as the custodian agency, will track post-harvest losses and progress against SDG Target 12.3.1.a at the global level, report on changes in the Global FLI and assist countries in compiling their own national FLIs. This annex will describe the salient methodological aspects developed for estimating the FLP and the FLI.

1. FLI AND FLP DESIGN

The FLI has a traditional Laysperes fixed-base formula comparing percentage losses of country (*i*) in a current period (*t*) to the percentage losses in the base period (*t₀*) for a basket of commodities (*j*), using value of production ($q_{ijt_0} * p_{jt_0}$) in the base period as the weights. The index is a composite of commodities that are key in national agricultural production or food systems, including crops, livestock and fisheries. It tracks losses as a percentage of total supply (l_{ijt}) in order to exclude the impact of production variability on losses measured in weight. The index formula is:

$$FLI_{it} = \frac{\sum_j l_{ijt} * (q_{ijt_0} * p_{jt_0})}{\sum_j l_{ij0} * (q_{ijt_0} * p_{jt_0})} * 100$$

The indices are also equal to the ratio of an average FLP in the current period and the FLP in the base period (multiplied by 100) and can be expressed with the following alternative and simpler formula:

$$FLI_{it} = \frac{FLP_{it}}{FLP_{it_0}} * 100$$

Where FLP_{it} is the country’s FLP, itself an aggregation of the loss percentages of each commodity l_{ijt} , weighted by its value of production. The FLP has been estimated and reported in this report at several aggregation levels:

$$FLP_{it} = \frac{\sum_j l_{ijt} * (q_{ijt_0} * p_{jt_0})}{\sum_j (q_{ijt_0} * p_{jt_0})}$$

The FLPs l_{ijt} which compile the national indices, and are the most critical pieces of information, will be the nationally representative loss

percentage for each commodity along the supply chain. In the absence of data, these percentages have been estimated with a model.

2. CONSTRUCTING THE FLI AND FLP

Selecting the commodities basket

Measuring post-harvest losses is especially complex and costly because of the multiple sources of losses, the many nodes of the supply chain where they can appear, and the difficulty of capturing them using either declarative or physical measurement techniques. In addition, it is not feasible to collect data in every year, for all commodities, at all stages. A review of loss reduction policies has shown that countries focus investment and decisions where the impact can be greatest, that is on a few strategic commodities, and that diverse diets and food security are key priorities related to this indicator.

No single list of ten commodities can be relevant for all countries, yet comparability is an important statistical quality. To allow for some international comparability while ensuring relevance, the basket is structured in five standard headings to cover the whole diet, and the two commodities per heading can indicate the variation in losses for each country within similar supply chains of each heading. Countries can go above and beyond and build on their experiences in measuring these ten commodities, as country priorities and resources allow.

The commodities baskets were set by applying the default method, where the country's production of primary commodities is ranked by economic value (using the international dollar price) and then sorted by the five headings: (i) cereals and pulses; (ii) fruits and vegetables; (iii) roots, tubers and oil-bearing crops; (iv) meat and animal products; (v) fish and fish products. For each heading, the top two items are selected. For a list of the commodities appearing in the basket of at least one country's FLI, see FAO, 2018.¹

Why focus on FLPs and not on quantities lost?

The FLI is based on the loss percentages for each commodity in the basket. This decision stemmed from the assumption that percentages will help isolate the signal and not the noise, as production varies from year to year and loss quantities will vary with total production, while long-term loss trends will be relatively stable and be a factor of other relevant indicators (e.g. investments, technology, incidence of pests, capacity of the supply chain, etc.).

This is especially visible when countries apply a constant loss factor based on expert opinion to estimate losses. In the anonymized example below (Figure A1), wheat losses were set at a flat 15 percent of supply across all years, yet total losses fluctuate over time in line with production. Carry-over factors are commonly used and occur in the dataset for the Food Balance Sheets (FBS) when new data collection or modelling are not applied, as well as in other data sources such as the African Postharvest Losses Information System (APHLIS).

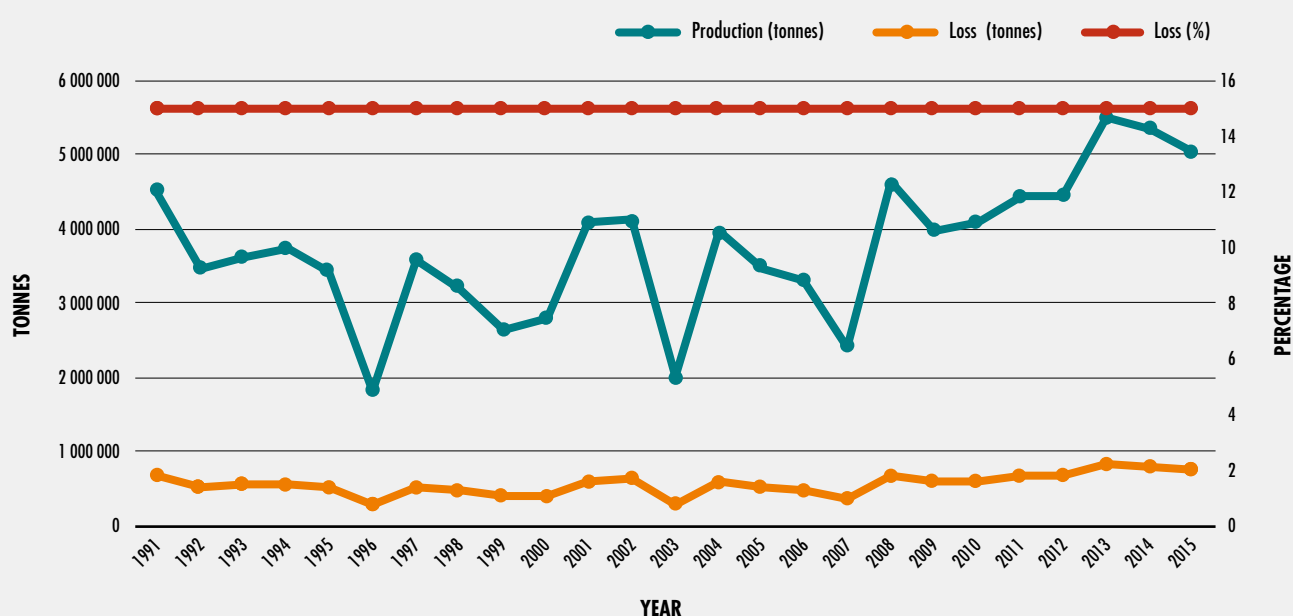
An index based on losses in tonnes would show annual variations and a trend, while the underlying loss factor is constant. The FLP and FLI are both constant in this case, neutralizing the noise coming from annual variations in production and yields.

Weighting pattern, reference period and scope of the FLP

After significant discussion, the chosen weights are in terms of the commodities' economic value of production on the assumption that markets operate efficiently in valuing the commodities' importance. While there are known biases in utilizing economic weights, it may be the least biased of the potential aggregation methods and provide a context for the cost-effectiveness of intervention strategies. The weights for the FLI and FLP are the value of the commodities baskets at an international average price in international dollar terms in the reference year.

When aggregating countries' loss percentages into regional or global losses, countries are weighed by their overall agricultural value,

FIGURE A1
WHEAT PRODUCTION AND LOSSES IN TONNES ESTIMATED APPLYING CONSTANT LOSSES
OF 15 PERCENT FACTOR



SOURCE: FAO, 2018¹

always in international dollar terms, relative to the rest of the world. In other words, the most valuable commodities will impact more on the FLP at country level and countries with larger agricultural sectors will weigh more heavily in the regional and global FLP estimates. However, with the selection of commodities across commodity headings, the production bias is overcome slightly, as different regions are major producers in different commodities.

The FLI and FLP scope in terms of the food supply chain starts on the farm after harvest and up to, but not including, the retail stage (see Chapter 1). The scope is different from that in the FAO 2011 study,² which included harvest losses as well as the demand-side of the food supply chain, which will be represented in the FWI under development. The division of the indicators

and estimates are due in part to the differences in the ability and cost in tracking losses and waste by individual commodities versus volume (as is the case for consumer waste) and the ability to focus on different policies that will target different stakeholders within countries. In cases where the countries can measure both indicators, a positive outcome will be if both indicators decrease.

3. ESTIMATING FLPs

Food loss data scarcity and the need to impute the missing data

Data scarcity is a leading issue in the introductory chapters of this report and the meta-analysis. Notwithstanding the fact that more than 40 years have passed since the first UN resolution to halve post-harvest

losses by 1985, the lack of data is still dire. These persisting data gaps have driven many decisions in designing the FLI methodology for the SDGs. One of the main limitations on measuring losses in the past has been the costliness of data collection along complex and far-reaching supply chains, which is still the main known challenge for most countries in obtaining the FLPs, by commodity over time. In order to increase the information base for SDG measuring and monitoring, FAO adopted a two-tier approach:

1. Improve the collection of data along the supply chain in the medium to long term with a range of possible surveys and other statistical tools to be integrated into national agricultural statistics systems. To this end, FAO has produced guidelines for countries on cost-effective methods to estimate food losses along the supply chain.
2. Use model-based loss estimates where data are not available in the short term. To this end, FAO developed an estimation model that incorporates explanatory variables grounded in reviewing available information at the stage, country and commodity level.³ The model will add value for countries seeking to both decrease losses and focus on factors that make the greatest impacts. A succinct description of the model follows below.

Data reported from countries through the FBS only covered 7 percent of the necessary commodities, countries and years needed for a full dataset. In addition, the national estimates using carry-overs provide a modelling challenge, indicating that losses do not change irrespective of policy and interventions. With the underlying paucity of basic loss data, the model did not display a significant trend following 2011, the benchmark year of FAO's earlier model.² Incorporation of secondary sources has improved the ability for the model to estimate losses for some regions and commodities; however, there are still untapped sources of information available and more movement is required towards measurement standards. The loss estimates in this report therefore refer to the latest available year, i.e. 2016, with currently

available information (which will be published concurrent to this report) and the default basket of commodities.

Justification for the model

Modelling efforts to estimate loss factors by country, commodity and year started as early as 2013. Two previous attempts, both using loss data from the Supply Utilization Accounts (SUA)/FBS, did not yield satisfactory results but provided the starting ground for the food loss modelled estimates used in this report.

Missing data proved to be a problem for both the independent and the dependent variables. The first model by Klaus Grünberger adopted an annual time trend, the percentage of paved roads in countries, GDP per capita and dummy variables for each region, single commodity and commodity group. Of the independent variables, only the commodity and the time trend were considered suitable and effective. The second model was a purely statistical hierarchical mixed-effect model that could be used to fill gaps but not for analytical purposes in looking at relationships between losses and explanatory factors.

The new model is structured to create a comparable, transparent method for countries that do not have officially reported data and to estimate loss while addressing many of the previous limitations. It builds on existing efforts and includes more policy-relevant variables and proxies for known causes of losses. Moreover, it was designed to provide a mechanism for aggregating losses at the stage level into a national estimate for each country/commodity/year along the whole supply chain, thus solving one of the under-coverage issues. It fosters a standardized, homogenous approach for estimating losses and selecting explanatory variables.

Input data

The model rests on three sets of input data: (i) officially reported loss data; (ii) information obtained through a literature review on food losses; and (iii) explanatory variables representing causal relationships with food losses found in the literature.

Officially reported loss data

Chapter 2 extensively describes the challenges of data collection and analyses available data density (or scarcity) in Figure 9, by use of heat maps. As mentioned in the chapter, only 39 countries have officially reported loss data through FAO's annual Agricultural Production Questionnaires for the period 1990–2017.

In the questionnaires, countries report on total losses at the national level for a whole tract of the supply chain defined the SUA/FBS framework with no breakdown by stages. These estimates from countries may be modelled, measured or come from a variety of internal sources and expert opinions. Countries may provide source documentation, if available, through the improved official loss questionnaire starting in 2019.

A preliminary analysis of the national derived loss percentages showed that they are lower than those found in the scientific literature and sector reports, even after aggregation to a national number. This is because, on the one hand, case studies and experiments are carried out where losses are reputed problematic and the results will therefore be higher than the national average; and, on the other hand, the SUA/FBS suffer from under-reporting by countries, which set losses to nil even on highly perishable products in the absence of information, and from underestimation in interview-based surveys.[†] An increase in the reported loss level must be therefore expected with the improvement of available data.

The estimation model had therefore to expand its input data to include loss percentages by stage from other available sources. However, this information is not used in the place of officially reported data; instead, it is used to inform the loss model estimations.

[†] A field test in Ghana highlighted systematic under-reporting by the farmers.⁴

Loss data from the literature review

An extensive review of literature in the public domain was carried out in 2016–17 and is still ongoing. It gathered additional information from almost 500 publications and reports from various sources (national institutions, academic institutions, international organizations such as the World Bank, GIZ, FAO, IFPRI, etc.).

In some cases, the studies were conducted to focus on a narrow slice of the food supply chain, which may also over-represent segments of the supply chain (e.g. storage has been widely analysed for grains and pulses) or segments of the population (e.g. smallholder farmers) that meet development objectives. At the opposite end, certain commodity groups are under-represented (fish and meat), as are the later stages of the supply chain. In addition, a critical loss point of harvest losses has not traditionally been collected as it occurs before the point at which production is measured and reported.

In many cases, the additional data allowed for considering losses at the various stages and then aggregating them to the national level. Although imperfect, these additional studies add necessary variation and potential upper bounds of what loss estimates may be in countries. However, the studies are also part of a country's overall loss estimation strategy in intermittent data collection years and thus use inconsistent data sources and methods.

The data have been used and extensively described for the meta-analysis in Chapter 2. They are organized in a database with many metadata dimensions and a user query interface. Links to the source document will be made available to the public on FAO's website.^u

Explanatory variables and their selection

A dataset of >200 possible explanatory variables was created tapping from various international databases (International Energy Agency, World Bank, FAO, etc.) to represent the numerous causal factors from the literature. Different proxies at

^u www.fao.org/food-loss-and-food-waste/flw-data

the national level as a means of measuring micro-level effects could be grouped under common themes to be managed by a single model. The common themes were: energy, inputs and associated costs; investment and monetary policy; social and economic factors; storage, transportation and logistics; weather and crop cycles.

The Random Forests algorithm was used to standardize the selection of variables and choose the five most important ones, by commodity grouping. The purpose was to better capture the variation in the causes of losses by country/region and commodity without limiting the potential by setting few factors applied widely without significance, as was the challenge remaining from the Grünberger approach.

Model specifications

A widely used econometric model, the Random Effects Model, has been chosen to exploit the data in a cross-section – by commodity and country – and longitudinally over time. The model assumes that the *index-specific effect* (that is, the country-commodity-specific effect) is a random variable uncorrelated with the explanatory variables selected. The model is specified as:

$$y_{ijt} = \alpha + x_{ijt}^T \beta + z_{ij}^T \gamma + u_{ijt}$$

where:

y_{ijt} is the percentage of food losses for the country i , for a given commodity, j , at time t

x_{ijt}^T is the k -dimensional row vector of time and commodity-varying explanatory variables

z_{ij}^T is an M -dimensional row vector of time-invariant dummy variables based on the indices i, j

u_{ijt} is the idiosyncratic error term

α is the intercept

Model assumptions

The model rests on a number of key assumptions:

Estimation of missing explanatory variable data

The explanatory variables time series are in some cases incomplete or low-frequency. The model fills in the missing data only after the Random Forest selects the variables, so as not to bias the time trends with potential smoothing efforts.

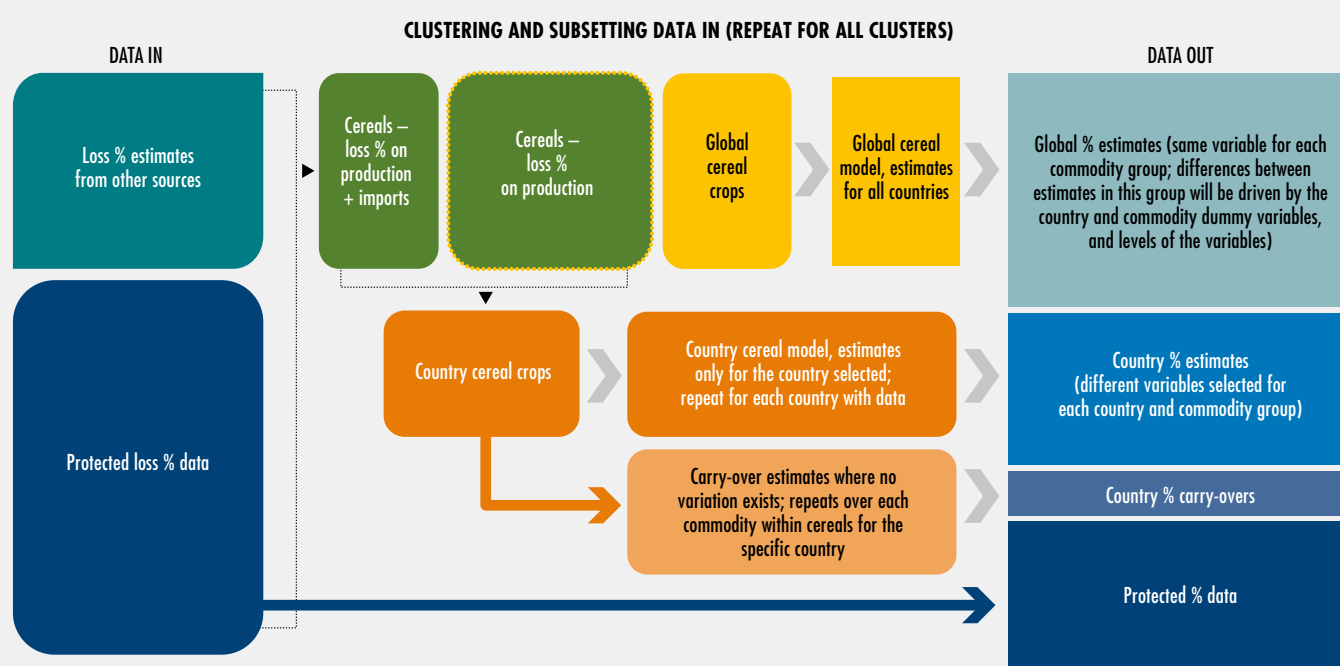
Use of clusters by commodity group and of a hierarchy of models

In many instances, there are fewer than three observations by country and commodity, which is considered a bare minimum to run the model for a country–commodity combination. In all those cases, available information has been clustered by commodity group on the assumption that causes and rates of losses are more similar within the groups than across them (for example, losses of maize and lentils are more similar than losses of maize and fresh milk); the same has been assumed for the types of value chain and solutions. Moreover, clustering scarce data will even out the impact of potential outliers on the results.

The coexistence of country-level estimates and cluster-level estimates requires a model hierarchy to fill in the results matrix. The process protects country-level official data and carry-over data (the cases where countries have in the past reported the same estimates from year to year) from being over-written by the model.

The model is then applied by country and commodity group, where loss data are available for different commodities in each group, to estimate the loss percentages for each of the five commodity groups. For example, if country A needs an estimate for wheat losses, the model draws on country A's "cereals and pulses" basket to create this estimate. This process repeats for all country–commodity and basket combinations where there is information for the other commodities in the basket. Each of these estimations will use a different selection of explanatory variables based on what is relevant for that country–commodity basket. For example, losses in country A may be correlated with the

FIGURE A2
GRAPHICAL REPRESENTATION OF THE MODEL



SOURCE: Fabi *et al.*, 2018³

price of transportation fuels, while in country B temperature and humidity may be more highly correlated with loss percentages.

In the remaining cases where a country does not have any loss data for an entire commodity heading, then the loss estimates come from a global model estimated by commodity heading. This indicates that country C's loss estimates may depend on what data are available in country A and country B. In some cases, the model may not perform well (e.g. when most estimates are flat carry-overs) as no factors can be correlated to the loss percentages. In these cases, a simple average of available loss factors by country-cluster is applied. Figure A2 illustrates the model flow.

Aggregation of loss factors by stage to the whole supply chain and imputation of the missing stages

While the officially reported data cover the whole supply chain, studies are rarely carried out across multiple stages of the food supply chain. To aggregate those loss factors along the supply chain, a simplified Markov process that assumes that losses at each point are independent of each other was used. Though losses may be caused by upstream behaviour, the *measured* losses at each stage are independent: for instance, losses due to poor handling in processing have no relationship with the losses that occurred in transportation. This process needed to be standardized given that studies would often add loss percentages across supply stages and not account for

the amount decreased (due to losses or own consumption) at each of the preceding stages.

In the case of some commodities, there was no information at all for some stages of the supply chain. For example, if country A measured losses of *x percent* in maize-storage-2000 and not in maize-storage-2001, losses in storage for 2001 would be considered as a zero. The Markov aggregation process in these cases produced biased results due to under-coverage over time. Losses for missing stages of the value chain have therefore been estimated using a simple ordinary least squares model with losses at each stage based on country, commodity or cluster, and time, and integrated in the Markov chain where the missing value was.

In other cases, more than one loss percentage was available for the same year-country-commodity-stage or year-country-cluster-stage combination. A simple average has been used in these cases before applying the simplified Markov process.

Final adjustments

In some cases, the input data may have been considered as outliers both on the high and on the low end of the distribution. Thresholds were set to exclude those outliers from the model, at three standard deviations below and above the whole dataset.

Very high percentage losses can be found in import-dependent countries, where loss quantities of imported products are compared to a small domestic production. An adjustment has

been made to the FLI methodology where the denominator in those cases is equal to domestic production plus import quantities. Very low percentages occur in some officially reported data, with losses lower than 2 percent across the whole supply chain.

An evolving process

With all its limitations, the food loss estimation model marks an important step forward in analysing, describing and estimating food losses at commodity, country and global level. Contrary to the FAO 2011 study on Food Losses and Waste,² the model is entirely open-source and estimates are reproducible. Moreover, the model can incorporate new information as it becomes available, including from new and available literature, and be tailored to countries without changing the structure. The literature review is still ongoing and data from a large number of studies are still to be added to the input dataset. Additional information on more countries and commodities certainly exists but has not been accessed yet. The model itself could be improved in some aspects, but the risk is to over-engineer it until it produces “expected” results on the same exceedingly weak information base.

The endeavour for the food losses and waste stakeholders and community should rather be to improve the loss data by supporting data collection in the countries to build a sound evidence base. Good-quality data will help in making informed decisions and in achieving national and global sustainability targets.

STATISTICAL ANNEX

NOTES ON THE STATISTICAL ANNEX

KEY

The following conventions are used in the tables:

.. = not available

0 or 0.0 = nil or negligible

Numbers presented in **Tables A2–A6** can be replicated starting from the original data sources and then following the operations of data management implemented through the Stata software, available upon request. To separate decimals from whole numbers, a full point (.) is used.

For **Tables A2–A6**:

- ▶ The **mean** (or average) is the resulting number determined by adding all the food loss and waste estimates reported in each respective variable (e.g. commodity group as shown in **Table A2**) and then dividing the total by the number of observations.
- ▶ **Median** is the value separating the higher half from the lower half of the food loss and waste estimates for each respective variable.
- ▶ The **standard deviation** measures the dispersion (i.e. the amount of variation) of the food loss and waste estimates. A low standard deviation signifies that the observations tend to be close to the mean (or average) of each respective variable.
- ▶ **Minimum** and **maximum** present the lowest and highest food loss and waste estimates of each variable, respectively.
- ▶ **Total** summarizes the statistics (observations, mean, median, standard deviation, minimum and maximum) for all of the food loss and waste estimates.

TABLE A1

List of countries officially reporting data on food loss to **FAO between 1990 and 2019, number of commodities in each commodity group**

Source: FAO. 2019. Questionnaire on Crop and Livestock Production and Utilization (2000–2017). Rome.

Cereals and pulses refer to the number of these commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

Fruits and vegetables refer to the number of these commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

Meat and animal products refer to the number of these commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

Roots, tubers and oil-bearing crops refer to the number of these commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

Other refers to the number of other commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

Total refers to the sum of commodities for which countries reported data on the losses in at least one year between 1990 and 2019.

For a list of the commodities appearing in the basket of at least one country's FLI, see: FAO. 2018. *Methodological proposal for monitoring SDG target 12.3. The Global Food Loss Index design, data collection methods and challenges*. Rome.

TABLE A2

Dataset of food loss and waste estimates from grey literature, national and sectoral reports, by commodity group between 2000 and 2017

Source: FAO. 2019. *Dataset of food loss estimates from grey literature, national and sectoral reports*. Online statistical working system for loss calculations (available at www.fao.org/food-loss-and-food-waste/flw-data).

Observations count the number of food loss and waste data points for each commodity group as reported in grey literature and national and sectoral reports, excluding the officially reported loss estimates.

Cereals refer to amaranth red, amaranths, bajra, barley, grains, millet, maize (corn), rice, rye, sabdariffa grain, sorghum, teff and wheat.

Pulses refer to yardlong bean, beans, dry beans, dry chickpeas, cowpea, field peas, gram black, gram green, green peas, legumes and pigeon peas.

Fruits refer to apples, apricots, peaches, plums, avocados, citrus, figs, fresh fruits, processed fruits, grapes, guava, jackfruit, kinnow, kiwi fruits, litchis, mandarin, mango, oranges, papayas, pears, persimmons, pineapples, plantains, plums, sloes, pomegranate, raspberries, strawberries and sweet cherries.

Vegetables refer to broccoli, cabbages, carrots, cauliflowers, Chinese cabbage, Chinese kale, cucumber, eggplant, garlic stalks, lettuce, mushrooms, okra, onions, Oriental bunching onion, pak choi, radish, tomatoes, other fresh vegetables and processed vegetables.

Meat refers to chicken, other poultry, pork and other meats.

Animal products refer to eggs, milk (fluid and other) and other dairy products, fish (inland and marine) and seafood.

Oil-bearing crops refer to coconut, cottonseeds, fats and oils, groundnuts, safflower, sesame seeds, soybeans, sunflower and sunflower seed.

Roots and tubers refer to fresh cassava, dried cassava, sweet potatoes, sweet potato leaves, tapioca, yams and potatoes.

Other commodities refer to spices (bell peppers, black peppers, chillies, Chinese hot peppers, coriander, mustard, sweet peppers, turmeric), sugars and syrups (sugar cane and sapota sweeteners) and tree nuts and ground nuts.

TABLE A3

Dataset of food loss and waste estimates from grey literature, national and sectoral reports, by region between 2000 and 2017

Source: see [Table A2](#).

Observations count the number of food loss and waste data points for each region as reported in grey literature and national and sectoral reports, excluding the officially reported loss estimates.

There are no data for Western Asia, Northern and Southern Africa, Australia and New Zealand, Micronesia and Polynesia, and Eastern and Southern Europe.

Northern America in the dataset refers to the United States of America only.

TABLE A4

Dataset of food loss and waste estimates from grey literature, national and sectoral reports, by food supply chain stage between 2000 and 2017

Source: see [Table A2](#).

Observations count the number of food loss and waste data points for each food supply chain stage as reported in grey literature and national and sectoral reports, excluding the officially reported loss estimates.

TABLE A5

Dataset of food loss and waste estimates from grey literature, national and sectoral reports, by data collection method between 2000 and 2017

Source: see [Table A2](#).

Observations count the number of food loss and waste data points for each data collection method as reported in grey literature and national and

sectoral reports, excluding the officially reported loss estimates.

Data collection methods used

The most used data collection method is the **survey**, i.e. interviews with a defined set of questions. Surveys considered in the dataset have a sampling methodology and a frame predetermined to the collection of information.

The **literature review** method is when losses or waste are based on findings from the literature.

The **expert opinion** method consists in the advice, belief or judgement given by an expert on the losses or waste.

The **rapid assessment** data collection method can be described as assessing a product via a visual damage scale and then the estimation of sample weight loss or waste by using a simple equation. In the database, rapid assessments include collecting information from a variety of stakeholders and sources, such as semi-structured interviews, reviews of existing estimates and development of the broad structure and flow of a commodity within a country. They can focus on a specific group or area of the supply chain and identify critical loss points. No direct measurement or systematic surveying across the wider population is done.

Case studies examine food losses or waste of specific persons or groups over a period of time. Case studies are often limited to a small set of participants, which may or may not be representative of the overall population.

Crop cutting includes direct measurement of a pre-sampled area of production and follows the local harvesting practices. This is a cost-intensive measurement that can benchmark “survey-interview-only” questionnaires.

Field trials estimate losses or waste via random assignment after field studies. They are experiments undertaken at an extension farm or semi-controlled for aspects related to the outcomes of an experiment, but non-laboratory based. They often produce loss factors for

farming/harvest/catch/slaughter practices but also for wholesale and retail stages.

Laboratory trials evaluate losses or waste via random assignment after trials conducted not in the field. Laboratory trials are done in a fully controlled environment, often with small sample sizes, and probably do not mimic the conditions that would occur under normal circumstances of practice.

Modelled estimates refer to estimation of losses or waste via statistical models.

The **World Resources Institute Protocol** provides loss and waste estimates. However, the protocol does not predefine a method of data collection nor does it require consistency across entities on what data are collected. As such, entities doing the measurement that use this protocol may have comparable results over time, but results may not be expandable for a wider sample or population.

TABLE A6

Dataset of food loss and waste estimates from grey literature, national and sectoral reports, by country between 2000 and 2017

Source: see Table A2.

Observations count the number of food loss and waste data points for each country as reported in grey literature and national and sectoral reports, excluding the officially reported loss estimates.

TABLE A7

Carbon impact factors (tonne CO₂ equivalent/tonne of food lost) used in Figures 13 and 14

Source: Data elaboration based on inputs (available upon request) developed for FAO. 2013. *Food Wastage Footprint: Impacts on Natural Resources – Summary Report*. Rome.

Carbon impact factors measure the carbon footprint of a specific food product by expressing 1 tonne of that food product in 1 tonne of CO₂ equivalent, in each stage of the food supply chain. The employed impact factors cover the food supply chain from farm up to and including retail. Given that GHG emissions accumulate

as food moves along the food supply chain, the retail stage has the largest carbon impact factor.

The carbon footprint of lost food is then expressed as a multiplication of the lost food quantities, in tonnes, provided by the model developed for the FLI, and the correspondent carbon impact factor. **Minimum** and **maximum** present the lowest- and highest-impact factors for each specific region and food group and the **average** is the average impact factor for each specific region and food group, across the food supply chain.

TABLE A8
Blue-water impact factors (m³/tonne of food lost) used in Figures 13 and 14
Source: see [Table A7](#).

Blue-water impact factors measure the blue-water footprint of a specific food product by expressing 1 tonne of food in cubic metres (m³) of blue water used to produce that tonne of food, in each stage of the food supply chain. The employed impact factors cover the food supply chain from farm up to and including retail. Given the assumption that blue water is used during agricultural production only, the blue-water impact factors remain the same at all stages of the food supply chain.

The blue-water footprint of lost food is then expressed as a multiplication of the lost food quantities, in tonnes, provided by the model developed for the FLI, and the correspondent blue-water impact factor. **Minimum** and **maximum** present the lowest and highest impact factors for each specific region and food group and the **average** is the average impact factor for each specific region and food group, across the food supply chain.

TABLE A9
Land impact factors (ha/tonne of food lost) used in Figures 13 and 14
Source: see [Table A7](#).

Land impact factors measure the land footprint of a specific food product by expressing 1 tonne of food in hectares (ha) of land used to produce that tonne of food. The employed impact factors

cover the food supply chain from farm up to and including retail. Given that the primary production stage accounts for nearly all land used to produce food, the land impact factors remain the same at all stages in the food supply chain.

The land footprint of lost food is then expressed as a multiplication of the lost food quantities, in tonnes, provided by the model developed for the FLI, and the correspondent land impact factor. **Minimum** and **maximum** present the lowest and highest impact factors used from the inputs for FAO (2013) whereas the **average** represents the average impact factor of the specific region and food group, across the food supply chain.

COUNTRY GROUPS AND REGIONAL AGGREGATES

Regional groupings and the designation of names of the countries follow the UNSD M49 classification of the United Nations Statistics Division, available at:
<https://unstats.un.org/unsd/methodology/m49/>

TABLE A1
LIST OF COUNTRIES OFFICIALLY REPORTING DATA ON FOOD LOSS TO FAO BETWEEN 1990 AND 2019,
NUMBER OF COMMODITIES IN EACH COMMODITY GROUP

COUNTRY/TERRITORY	Cereals and pulses	Fruits and vegetables	Meat and animal products	Roots, tubers and oil-bearing crops	Other	Total
AFRICA						
Sub-Saharan Africa						
Eastern Africa						
Eritrea	6	0	0	0	0	6
Ethiopia	2	0	0	0	0	2
Malawi	2	0	0	0	0	2
Mauritius	1	6	1	1	0	9
Rwanda	4	0	0	3	0	7
Zambia	2	0	0	0	0	2
Middle Africa						
Chad	4	0	0	0	0	4
Democratic Republic of the Congo	1	0	0	0	0	1
Southern Africa						
Western Africa						
Mali	5	0	0	5	0	10
Togo	5	0	0	1	0	6
Northern Africa						
Algeria	0	0	0	0	1	1
Egypt	9	0	0	8	1	18
Sudan	5	0	0	0	0	5
ASIA						
Western Asia						
Armenia	6	1	0	1	0	8
Azerbaijan	6	1	0	1	0	8
Cyprus	1	0	0	0	0	1
Georgia	2	1	0	1	0	4
Israel	0	1	1	1	0	3
Jordan	2	0	0	2	0	4
Syrian Arab Republic	1	0	0	0	0	1
Central Asia						
Kazakhstan	5	0	3	2	1	11
Kyrgyzstan	0	0	0	0	0	0
Tajikistan	0	0	0	1	0	1
Eastern Asia						
Japan	4	0	2	3	0	9
Republic of Korea	2	0	0	1	0	3
South-eastern Asia						
Indonesia	2	1	1	4	0	8
Myanmar	0	0	0	1	0	1
Philippines	2	0	0	0	0	2
Viet Nam	1	0	0	0	0	1

**TABLE A1
(CONTINUED)**

COUNTRY/TERRITORY	Cereals and pulses	Fruits and vegetables	Meat and animal products	Roots, tubers and oil-bearing crops	Other	Total
Southern Asia						
Afghanistan	4	0	0	0	0	4
India	4	0	0	0	0	4
Iran (Islamic Republic of)	0	0	2	0	0	2
Nepal	3	0	0	1	0	4
Pakistan	2	0	0	0	0	2
Sri Lanka	3	0	0	3	0	6
EUROPE						
Eastern Europe						
Belarus	0	0	2	0	0	2
Czechia	4	0	0	0	0	4
Hungary	14	20	4	7	0	45
Poland	10	7	2	6	1	26
Republic of Moldova	0	0	0	2	0	2
Romania	6	8	0	1	1	16
Russian Federation	0	0	2	1	0	3
Slovakia	3	0	0	1	0	4
Ukraine	11	0	2	1	0	14
Northern Europe						
Denmark	7	0	0	0	0	7
Estonia	4	0	0	1	0	5
Ireland	3	0	0	0	0	3
Latvia	4	0	1	0	0	5
Lithuania	10	0	1	1	0	12
Norway	0	0	0	1	0	1
Sweden	5	0	1	1	0	7
United Kingdom of Great Britain and Northern Ireland	3	6	1	0	0	10
Southern Europe						
Albania	0	0	2	0	0	2
Bosnia and Herzegovina	0	1	0	0	0	1
Croatia	0	1	0	0	0	1
Italy	2	2	1	0	0	5
North Macedonia	7	0	0	4	0	11
Portugal	1	0	0	0	0	1
Serbia	2	0	5	0	0	7
Spain	4	0	0	1	0	5
Western Europe						
Austria	12	15	3	6	0	36
Belgium	2	0	1	1	0	4
France	8	1	3	2	0	14
Germany	9	0	1	5	0	15
Luxembourg	2	0	0	1	0	3
Netherlands	5	2	1	1	0	9
Switzerland	6	0	0	1	0	7

**TABLE A1
(CONTINUED)**

COUNTRY/TERRITORY	Cereals and pulses	Fruits and vegetables	Meat and animal products	Roots, tubers and oil-bearing crops	Other	Total
LATIN AMERICA AND THE CARIBBEAN						
Caribbean						
Cuba	2	7	0	2	0	11
Jamaica	4	1	0	3	0	8
Central America						
Guatemala	5	5	1	0	2	13
Mexico	2	0	0	0	0	2
Nicaragua	0	0	0	0	0	0
Panama	6	4	5	4	1	20
South America						
Argentina	0	0	1	0	0	1
Bolivia (Plurinational State of)	1	0	0	3	0	4
Ecuador	8	22	0	6	1	37
Peru	16	38	8	9	6	77
Venezuela (Bolivarian Republic of)	7	10	6	7	2	32
NORTHERN AMERICA						
Canada	9	27	2	0	0	38
United States of America	0	0	0	2	3	5
OCEANIA						
Australia/New Zealand						
New Zealand	2	0	0	0	0	2
Melanesia						
Fiji	3	1	0	4	0	8
New Caledonia	2	0	0	0	0	2
Micronesia						
Polynesia						

**TABLE A2
DATASET OF FOOD LOSS AND WASTE ESTIMATES FROM GREY LITERATURE, NATIONAL AND SECTORAL REPORTS,
BY COMMODITY GROUP BETWEEN 2000 AND 2017**

Commodity group	Observations	Mean	Median	Standard deviation	Min	Max
Cereals and pulses	650	4.6	1.3	8.3	0.0	89.5
Fruits and vegetables	756	6.9	3.0	10.3	0.0	75.4
Meat and animal products	215	2.6	0.8	5.4	0.0	37.0
Roots, tubers and oil-bearing crops	364	4.1	1.0	8.4	0.0	72.0
Other	307	1.2	0.3	2.9	0.0	33.7
Total	2 292	4.6	1.4	8.6	0.0	89.5

TABLE A3
DATASET OF FOOD LOSS AND WASTE ESTIMATES FROM GREY LITERATURE, NATIONAL AND SECTORAL REPORTS, BY REGION BETWEEN 2000 AND 2017

SDG region	Observations	Mean	Median	Standard deviation	Min	Max
Central and Southern Asia	1 524	2.2	0.6	5.4	0.0	75.4
Eastern and South-eastern Asia	203	7.8	5.5	7.9	0.0	50.0
Latin America and the Caribbean	40	9.9	8.8	7.3	0.8	42.5
Northern America and Europe	141	9.8	7.0	9.5	0.0	69.4
Oceania	3	5.1	6.4	4.5	0.1	8.8
Sub-Saharan Africa	381	10.1	5.0	13.3	0.0	89.5
Total	2 292	4.6	1.4	8.6	0.0	89.5

TABLE A4
DATASET OF FOOD LOSS AND WASTE ESTIMATES FROM GREY LITERATURE, NATIONAL AND SECTORAL REPORTS, BY FOOD SUPPLY CHAIN STAGE BETWEEN 2000 AND 2017

Stage of food supply chain	Observations	Mean	Median	Standard deviation	Min	Max
On-farm post-harvest/slaughter	1 163	3.3	0.8	7.3	0.0	81.5
Storage	507	4.9	1.1	9.5	0.0	89.5
Transportation	140	6.7	3.4	9.5	0.1	74.0
Processing and packaging	173	5.6	1.7	9.7	0.0	69.4
Wholesale and retail	279	6.8	4.5	8.8	0.0	75.4
Consumption: households and food services	30	14.9	15.0	9.1	1.0	37.0
Total	2 292	4.6	1.4	8.6	0.0	89.5

TABLE A5
DATASET OF FOOD LOSS AND WASTE ESTIMATES FROM GREY LITERATURE, NATIONAL AND SECTORAL REPORTS, BY DATA COLLECTION METHOD BETWEEN 2000 AND 2017

Method of data collection	Observations	Mean	Median	Standard deviation	Min	Max
Case study	60	11.4	5.3	16.0	0.5	79.0
Crop cutting field	8	4.4	3.4	2.9	2.3	10.6
Expert opinion	142	7.5	4.7	9.1	0.0	50.0
Field trial	24	13.0	6.7	14.9	1.1	57.3
Laboratory trial	12	26.5	20.0	23.4	2.5	72.0
Literature review	454	4.8	1.2	8.6	0.0	74.0
Modelled	42	13.7	12.0	7.7	4.0	37.0
Rapid assessment	105	13.5	9.5	14.9	0.2	89.5
Survey	1 367	2.5	0.7	5.2	0.0	69.4
World Resources Institute Protocol	46	4.9	3.0	5.9	0.0	30.0
Not specified	32	9.3	6.1	8.0	0.5	26.7
Total	2 292	4.6	1.4	8.6	0.0	89.5

TABLE A6
DATASET OF FOOD LOSS AND WASTE ESTIMATES FROM GREY LITERATURE, NATIONAL AND SECTORAL REPORTS,
BY COUNTRY BETWEEN 2000 AND 2017

COUNTRY/TERRITORY	Observations	Mean	Median	Standard deviation	Min	Max
AFRICA						
Sub-Saharan Africa						
Eastern Africa						
Ethiopia	10	6.0	4.6	4.7	0.1	14.9
Kenya	31	9.0	6.0	10.2	0.2	40.0
Madagascar	8	1.8	1.6	0.6	1.0	2.5
Malawi	14	10.2	10.5	5.5	1.4	20.3
Mozambique	8	14.0	14.5	13.5	0.0	43.0
Rwanda	16	14.9	14.8	7.0	4.9	26.7
Uganda	10	8.3	4.4	10.3	2.0	35.0
United Republic of Tanzania	50	12.8	8.4	12.8	0.0	63.0
Middle Africa						
Cameroon	1	35.0	35.0	..	35.0	35.0
Gabon	1	35.0	35.0	..	35.0	35.0
Northern Africa						
Southern Africa						
Western Africa						
Benin	21	29.6	22.0	26.3	1.6	89.5
Burkina Faso	2	1.6	1.6	0.4	1.3	1.9
Gambia	1	12.8	12.8	..	12.8	12.8
Ghana	131	8.3	2.5	13.5	0.0	72.0
Niger	5	13.3	15.0	3.5	8.6	17.1
Nigeria	67	6.1	4.4	6.3	0.1	28.0
Sierra Leone	5	6.6	6.6	1.1	5.0	8.0
ASIA						
Western Asia						
Central Asia						
Kazakhstan	5	12.3	12.5	5.9	4.0	20.0
Eastern Asia						
China	106	8.1	5.0	9.5	0.0	50.0
Republic of Korea	29	13.8	14.0	3.9	8.0	24.0
South-eastern Asia						
Cambodia	14	5.5	4.3	2.6	3.0	12.5
Indonesia	9	3.6	1.2	4.7	0.2	15.0
Malaysia	5	5.6	6.0	2.5	2.0	9.0
Philippines	17	6.9	8.4	4.4	1.0	15.5
Thailand	3	7.0	8.5	4.0	2.5	10.0
Timor-Leste	19	2.3	1.3	2.5	0.5	10.0
Viet Nam	1	2.0	2.0	..	2.0	2.0
Southern Asia						
Bangladesh	89	7.4	7.2	4.6	0.2	35.0
India	1 296	1.0	0.4	2.9	0.0	62.5
Iran (Islamic Republic of)	69	4.8	3.0	4.4	1.0	16.5

**TABLE A6
(CONTINUED)**

COUNTRY/TERRITORY	Observations	Mean	Median	Standard deviation	Min	Max
Nepal	43	15.5	10.0	14.7	0.6	74.0
Pakistan	22	12.2	5.0	17.7	0.0	75.4
EUROPE						
Eastern Europe						
Northern Europe						
Denmark	13	9.4	5.6	6.7	0.0	21.0
Finland	9	9.4	6.2	6.1	2.3	17.7
Norway	12	11.0	6.1	19.0	0.9	69.4
Sweden	16	14.2	14.3	10.5	0.2	33.5
United Kingdom of Great Britain and Northern Ireland	46	4.9	3.0	5.9	0.0	30.0
Southern Europe						
Western Europe						
Switzerland	2	0.0	0.0	0.0	0.0	0.0
LATIN AMERICA AND THE CARIBBEAN						
Caribbean						
Haiti	1	20.0	20.0	..	20.0	20.0
Central America						
Guatemala	5	15.6	14.7	16.2	2.9	42.5
Honduras	4	8.6	8.5	5.5	3.7	13.7
Mexico	13	8.0	7.7	5.4	0.8	20.0
South America						
Brazil	12	10.0	11.6	3.6	2.4	16.0
Ecuador	2	6.5	6.5	5.7	2.5	10.5
Peru	3	8.8	9.6	6.2	2.3	14.5
NORTHERN AMERICA						
United States of America	43	13.7	12.0	7.6	4.0	37.0
OCEANIA						
Australia/New Zealand						
Melanesia						
Fiji	3	5.1	6.4	4.5	0.1	8.8
Micronesia						
Polynesia						
Total	2 292	4.6	1.4	8.6	0.0	89.5

TABLE A7
CARBON IMPACT FACTORS (TONNE CO₂ EQUIVALENT/TONNE OF FOOD LOST) USED IN FIGURES 13 AND 14

SDG region	Cereals and pulses			Fruits and vegetables			Meat and animal products			Roots, tubers and oil-bearing crops		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Australia and New Zealand	0.4	2.2	1.6	0.3	2.8	1.8	0.7	1.7	1.4	0.2	0.8	0.6
Central and Southern Asia	0.5	3.3	2.2	0.1	1.8	1.1	1.0	5.5	2.3	0.1	1.6	1.0
Eastern and South-eastern Asia	0.6	3.7	2.6	0.2	1.2	1.0	4.5	6.5	5.6	0.4	1.1	1.0
Latin America and the Caribbean	0.1	3.3	1.7	0.1	1.5	1.1	0.7	6.1	4.4	0.1	2.4	1.3
Northern America and Europe	0.4	1.9	1.5	0.3	3.0	1.5	0.7	2.0	1.6	0.2	0.9	0.7
Oceania (excluding Australia and New Zealand)	0.5	3.3	2.3	0.3	1.4	1.1	0.7	6.0	3.6	1.6	2.4	2.3
Sub-Saharan Africa	0.1	5.3	1.9	0.1	1.5	0.5	1.0	6.2	2.3	0.1	1.2	0.5
Western Asia and Northern Africa	0.8	2.7	2.0	0.5	1.7	1.3	1.0	5.6	4.2	0.1	1.7	1.1

TABLE A8
BLUE-WATER IMPACT FACTORS (M³/TONNE OF FOOD LOST) USED IN FIGURES 13 AND 14

SDG region	Cereals and pulses			Fruits and vegetables			Meat and animal products			Roots, tubers and oil-bearing crops		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Australia and New Zealand	16.5	98.1	57.3	124.1	301.8	212.9	82.0	82.0	82.0	96.7	96.7	96.7
Central and Southern Asia	77.5	1 177.8	609.1	95.9	301.8	266.7	212.1	1 018.6	564.6	50.6	3 100.5	741.8
Eastern and South-eastern Asia	57.9	202.1	130.0	301.8	301.8	301.8	179.9	188.3	181.6	17.9	17.9	17.9
Latin America and the Caribbean	22.4	383.4	146.9	72.1	301.8	271.8	46.0	268.8	168.1	8.5	74.3	28.0
Northern America and Europe	38.9	124.4	64.3	33.3	301.8	242.3	61.1	77.3	65.2	9.0	158.6	39.7
Oceania (excluding Australia and New Zealand)	21.3	687.3	354.3	301.8	301.8	301.8	92.7	256.6	174.7	14.0	14.0	14.0
Sub-Saharan Africa	7.0	631.3	146.7	44.8	301.8	239.9	59.3	218.6	161.5	1.3	339.7	147.9
Western Asia and Northern Africa	322.3	1 008.5	538.0	158.0	301.8	226.8	497.7	1 217.0	977.3	185.4	1 501.3	624.1

TABLE A9
LAND IMPACT FACTORS (HA/TONNE OF FOOD LOST) USED IN FIGURES 13 AND 14

SDG region	Cereals and pulses			Fruits and vegetables			Meat and animal products			Roots, tubers and oil-bearing crops		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Australia and New Zealand	0.7	0.9	0.8	0.0	0.1	0.1	2.5	2.5	2.5	0.0	0.0	0.0
Central and Southern Asia	0.2	0.8	0.4	0.0	0.1	0.1	4.6	18.9	12.6	0.1	0.5	0.2
Eastern and South-eastern Asia	0.3	0.3	0.3	0.1	0.1	0.1	11.6	12.6	11.8	0.2	0.2	0.2
Latin America and the Caribbean	0.2	1.2	0.6	0.1	0.1	0.1	3.4	5.5	4.0	0.1	0.4	0.2
Northern America and Europe	0.1	0.4	0.3	0.0	0.1	0.1	0.7	2.5	1.2	0.0	0.3	0.1
Oceania (excluding Australia and New Zealand)	0.3	0.8	0.5	0.1	0.1	0.1	3.4	5.5	4.5	0.3	0.3	0.3
Sub-Saharan Africa	0.3	2.4	0.9	0.1	0.2	0.1	9.3	19.8	17.0	0.1	1.1	0.6
Western Asia and Northern Africa	0.1	1.4	0.9	0.1	0.1	0.1	18.9	34.3	0.2	0.1	0.5	29.1

REFERENCES

CHAPTER 1

1. Searchinger, T., Waite, R., Hanson, C., Ranganathan, J., Dumas, P. & Matthews, E. 2018. *Creating a sustainable food future – a menu of solutions to feed nearly 10 billion people by 2050*. Washington, DC, World Resources Institute. [also available at <https://www.wri.org/publication/creating-sustainable-food-future>].
2. Chaboud, G. & Daviron, B. 2017. Food losses and waste: navigating the inconsistencies. *Global Food Security*, 12: 1–7.
3. Bellemare, M.F., Çakir, M., Peterson, H.H., Novak, L. & Rudi, J. 2017. On the Measurement of Food Waste. *American Journal of Agricultural Economics*, 99(5): 1148–1158.
4. Delgado, L., Schuster, M. & Torero, M. 2019. Quantity and quality food losses across the value chain: a comparative analysis. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. Washington, DC, IFPRI. Unpublished.
5. WHO & FAO. 2013. *Codex Alimentarius Commission – Procedural Manual*. Twenty-First edition. Rome, Secretariat of the Joint FAO/WHO Food Standards Programme.
6. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2014. *Food losses and waste in the context of sustainable food systems*. Rome.
7. Rutten, M.M. 2013. What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agriculture & Food Security*, 2(1): 13.
8. United States Department of Agriculture (USDA). 2019. *Food Service Industry* [online]. [Cited 11 June 2019]. <https://www.ers.usda.gov/topics/food-markets-prices/food-service-industry.aspx>
9. Champions 12.3. 2017. *Guidance on Interpreting Sustainable Development Goal Target 12.3*. Washington, DC.
10. Inter-agency and Expert Group on SDG Indicators (IAEG-SDGs). 2019. *Tier Classification for Global SDG Indicators*. New York, USA, Inter-agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs) and United Nations Statistics Division.
11. UNSD. 2018. *Goal 12*. New York, USA, United Nations Statistics Division (UNSD).
12. FAO. 2019. *Food Loss Index. Online statistical working system for loss calculations* [available at <http://www.fao.org/food-loss-and-food-waste/flw-data>].
13. FAO. 1998. *Storage and Processing of Roots and Tubers in the Tropics*. Rome.
14. FAO. 2011. *Global food losses and food waste – Extent, causes and prevention*. Rome.
15. FAO. 2018. *Methodological proposal for monitoring SDG target 12.3: the Global Food Loss Index design, data collection methods and challenges*. Rome.
16. Gustavsson, J., Cederberg, C., Sonesson, U. & Emanuelsson, A. 2013. *The methodology of the FAO study: “Global food losses and food waste – extent, causes and prevention”*. FAO, 2011. SIK report No. 857. Lund, Sweden, Swedish Institute for Food and Biotechnology (SIK).
17. Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O’Connor, C., Östergren, K. & Cheng, S. 2017. Missing food, missing data? A critical review of global food losses and food waste data. *Environmental Science & Technology*, 51(12): 6618–6633.
18. Kumm, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P.J. 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, 438: 477–489.
19. Segrè, A., Falasconi, L., Politano, A. & Vittuari, M. 2014. *Background paper on the economics of food loss and waste – working paper*. Save Food: Global Initiative on Food Loss and Waste Reduction – working paper. Rome, FAO.
20. Oxford Reference. 2019. *Opportunity cost* [online]. [Cited 9 May 2019]. <https://www.oxfordreference.com/view/10.1093/oi/authority.20110810105528518>
21. Anríquez, G., Foster, W., Santos-Rocha, J., Ortega, J. & Jansen, S. 2019. *Refining the definition of food loss and waste from an economic perspective: producers, intermediaries, and consumers as key decisionmakers*. Santiago, Department of Agricultural Economics, Pontifical Catholic University of Chile.

REFERENCES

22. Delgado, L., Schuster, M. & Torero, M. 2017. *Reality of food losses: a new measurement methodology*. IFPRI Discussion Paper 01686. Washington, DC, IFPRI.
23. The New Indian Express. 2018. Farmers dump tomatoes on roads as prices fall. In: *The New Indian Express* [online]. <http://www.newindianexpress.com/states/karnataka/2018/jun/26/farmers-dump-tomatoes-on-roads-as-prices-fall-1833732.html>
24. Lipinski, B., Hanson, C., Lomax, J., Kitinjoja, L., Waite, R. & Searchinger, T. 2013. *Reducing food loss and waste. Installment Two of 'Creating a sustainable food future'*. Working Paper. Washington, DC, World Resources Institute.
25. Gromko, D. & Abdurasulova, G. 2018. *Climate change mitigation and food loss and waste reduction: exploring the business case*. Working Paper No. 246. Wageningen, The Netherlands, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
26. Gravelle, H. & Rees, R. 2004. *Microeconomics*. 3rd edition. Harlow, Financial Times/Prentice Hall.
27. Varian, H.R. 1992. *Microeconomic analysis*. 3rd edition. New York, USA, Norton.
28. Krugman, P.R. & Wells, R. 2013. *Economics*. 3rd edition. New York, USA, Worth Publishers.
29. Heller, W.P. 1999. Equilibrium market formation causes missing markets. *Markets, Information and Uncertainty: Essays in Economic Theory in Honor of Kenneth J. Arrow*: 235.
30. Burningham, D. & Davies, J. 2004. *Environmental Economics*. Oxford, UK, Heinemann.
31. Wijewardena, W.A. 2011. Why did the good-intentioned public intervention go wrong? In: *FT Online* [online]. <http://www.ft.lk/columns/why-did-the-good-intentioned-public-intervention-go-wrong/4-61137>
4. FAO. 2018. State of Food and Agriculture in Asia and the Pacific Region, including Future Prospects and Emerging Issues. Thirty-fourth Session. Paper presented at Regional Conference for Asia and the Pacific (APRC), 9 April 2018, Nadi, Fiji.
5. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2014. *Food losses and waste in the context of sustainable food systems*. Rome.
6. FAO. 2011. *Global food losses and food waste – Extent, causes and prevention*. Rome.
7. Goldsmith, P.D., Martins, A.G. & de Moura, A.D. 2015. The economics of post-harvest loss: a case study of the new large soybean – maize producers in tropical Brazil. *Food Security*, 7(4): 875–888.
8. Kitinjoja, L. & Kader, A.A. 2002. *Small-scale postharvest handling practices: a manual for horticultural crops*. 4th edition. University of California, Davis, Postharvest Technology Research and Information Center.
9. Kaaya, A., Kyamuhangire, W. & Kyamanywa, S. 2006. Factors affecting aflatoxin contamination of harvested maize in the three agroecological zones of Uganda. *Journal of Applied Sciences*, 6(11): 2401–2407.
10. FAO. 2018. *Étude diagnostique de la réduction des pertes après récolte de trois cultures: manioc – tomate – pomme de terre*. Rapport de synthèse: Cameroun. Rome.
11. Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Lubber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A.M., Misore, A., DeCock, K. & Rubin, C. 2005. Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in eastern and central Kenya. *Environmental Health Perspectives*, 113(12): 1763–1767.
12. Kaaya, A.N., Warren, H.L., Kyamanywa, S. & Kyamuhangire, W. 2005. The effect of delayed harvest on moisture content, insect damage, moulds and aflatoxin contamination of maize in Mayuge district of Uganda. *Journal of the Science of Food and Agriculture*, 85(15): 2595–2599.
13. Delgado, L., Schuster, M. & Torero, M. 2017. *Reality of food losses: a new measurement methodology*. IFPRI Discussion Paper 01686. Washington, DC, IFPRI.
14. Delgado, L., Schuster, M. & Torero, M. 2019. Quantity and quality food losses across the value chain: a comparative analysis. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. Washington, DC, IFPRI. Unpublished.
15. Ambler, K., De Brauw, A. & Godlonton, S. 2018. Measuring postharvest losses at the farm level in Malawi. *The Australian Journal of Agricultural and Resource Economics*, 62(1): 139–160.

CHAPTER 2

1. FAO. 2019. Food Loss Index. Online statistical working system for loss calculations [available at <http://www.fao.org/food-loss-and-food-waste/flw-data>].
2. FAO. 2019. Dataset of food loss and waste estimates from grey literature, national and sectoral reports. Online statistical working system for loss calculations [available at <http://www.fao.org/food-loss-and-food-waste/flw-data>].
3. Nanda, S.K., Vishwakarma, R., Bathla, H.V.L., Rai, A. & Chandra, P. 2012. *Harvest and post harvest losses of major crops and livestock produce in India*. Ludhiana, India.

16. Abdoulaye, T., Ainembabazi, J.H., Alexander, C., Baributsa, D., Kadjo, D., Moussa, B., Omotilewa, O., Ricker-Gilbert, J. & Shiferaw, F. 2016. *Postharvest loss of maize and grain legumes in sub-Saharan Africa: insights from household survey data in seven countries*. West Lafayette, IN, USA, Purdue Extension Agricultural Economics.
17. John, A. 2014. Rodent outbreaks and rice pre-harvest losses in Southeast Asia. *Food Security*, 6(2): 249–260.
18. Tefera, T. 2012. Post-harvest losses in African maize in the face of increasing food shortage. *Food Security*, 4(2): 267–277.
19. HLPE. 2014. *Sustainable fisheries and aquaculture for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome.
20. Diei-Ouadi, Y. & Mgawe, Y.I. 2011. *Post-harvest fish loss assessment in small-scale fisheries: a guide for the extension officer*. FAO fisheries and aquaculture technical paper No. 559. Rome, FAO.
21. FAO. 2014. *Food loss assessments: causes and solutions. Case studies in small-scale agriculture and fisheries subsectors. Kenya: banana, maize, milk, fish. Global Initiative on Food Loss and Waste Reduction – Save Food*. Rome.
22. FAO. forthcoming. *Estudios de casos sobre la estimación de pérdidas de pescado en la cuenca amazónica*. Rome.
23. FAO. 2018. *The Republic of Rwanda: maize, potato, tomato, milk. Food loss analysis: causes and solutions. Case studies in the small-scale agriculture and fisheries subsectors*. Rome.
24. Nakasone, E., Delgado, L. & Vos, R. 2019. Determinants of farm post-harvest losses in developing countries. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. IFPRI.
25. World Bank. 2011. *Missing food: the case of postharvest grain losses in Sub-Saharan Africa*. World Bank, Other Operational Studies 2824. Washington, DC. [also available at <https://ideas.repec.org/p/wbk/wboper/2824.html>].
26. Bett, C. & Nguyo, R. 2007. Post-harvest storage practices and techniques used by farmers in semi-arid Eastern and Central Kenya. *8th African Crop Science Society Conference, El-Minia, Egypt, 27–31 October 2007*: 1023–1227.
27. Rolle, R.S. 2006. Improving postharvest management and marketing in the Asia-Pacific region: issues and challenges. *Postharvest management of fruit and vegetables in the Asia-Pacific region*, 1(1): 23–31.
28. IMechE (Institution of Mechanical Engineers). 2013. *Global food. Waste not, want not*. London.
29. Awono, A., Ingram, V., Schure, J. & Levang, P. 2013. *Guide for small and medium enterprises in the sustainable non-timber forest product trade in Central Africa*. Center for International Forestry Research (CIFOR). [also available at <http://www.cifor.org/library/4053/guide-for-small-and-medium-enterprises-in-the-sustainable-non-timber-forest-product-trade-in-central-africa>].
30. Kumar, D. & Kalita, P. 2017. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, 6(1). [also available at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5296677/>].
31. COMCEC Coordination Office. 2017. *Reducing food waste in the OIC countries*. Ankara, Standing Committee for Economic and Commercial Cooperation of the Organization of Islamic Cooperation (COMCEC).
32. Fonseca, J. & Vergara, N. 2015. *Logistics in the horticulture supply chain in Latin America and the Caribbean. Regional report based on five country assessments and findings from regional workshops*. Rome, FAO.
33. Parfitt, J., Barthel, M. & Macnaughton, S. 2010. Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554): 3065–3081.
34. Liu, G. 2014. *Food losses and food waste in China. A first estimate*. OECD Food, Agriculture and Fisheries Papers, No. 66. Paris, OECD Publishing.
35. FAO. 2016. *Developing the cold chain in the agrifood sector in Sub-Saharan Africa*. Agroindustry Policy Brief 2.
36. Kitinoja, L. 2013. Use of cold chains for reducing food losses in developing countries. No. 13-03. The Postharvest Education Foundation.
37. Salin, V. 2018. *2018 GCCA Cold storage capacity report*. Arlington, USA, Global Cold Chain Alliance.
38. Kitinoja, L. & AlHassan, H.Y. 2012. Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia – Part 1. Postharvest losses and quality assessments. *Acta Horticulturae*, 934(934): 31–40.
39. Rosegrant, M., Magalhaes, E., Valmonte-Santos, R. & Mason-D'Croz, D. 2015. *Returns to investment in reducing postharvest food losses and increasing agricultural productivity growth – Post-2015 consensus*. Food Security and Nutrition Assessment Paper. Copenhagen Consensus Center.
40. Martínez Z., N., Menacho P., Z. & Pachón-Ariza, F. 2014. Food loss in a hungry world, A problem? *Agronomía Colombiana*, 32(2): 283–293.
41. FAO. 2017. *Policy measures for managing quality and reducing post-harvest losses in fresh produce supply chains in South Asian Countries*. Rome. [also available at www.fao.org/3/a-i7954e.pdf].

REFERENCES

42. FAO. 2011. *Value chain development and post-harvest loss reduction for smallholders*. Rome. [also available at <http://www.fao.org/3/mc762e/mc762e.pdf>].
43. Rapusas, R. & Rolle, R. 2009. *Management of reusable plastic crates in fresh produce supply chains. A technical guide*. Bangkok, FAO Regional Office for Asia and the Pacific. [also available at www.fao.org/3/a-i0930e.pdf].
44. FAO. 2011. Packaging in fresh produce supply chains in Southeast Asia. Bangkok. [also available at www.fao.org/3/ba0135e/ba0135e00.htm].
45. 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. [also available at www.fao.org/3/i8616en/i8616en.pdf].
46. Alavi, H.R. 2011. *Trusting trade and the private sector for food security in Southeast Asia*. Directions in Development – General. The World Bank. [also available at <https://elibrary.worldbank.org/doi/abs/10.1596/978-0-8213-8626-2>].
47. Mena, C., Adenso-Diaz, B. & Yurt, O. 2011. The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling*, 55(6): 648–658.
48. FAO. 2018. *Methodological proposal for monitoring SDG target 12.3. The Global Food Loss Index design, data collection methods and challenges*. Rome, FAO Statistical Division.
49. Buzby, J.C., Farah-Wells, H. & Hyman, J. 2014. *The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States*. No. ID 2501659. Rochester, NY, Social Science Research Network.
50. Hanssen, O. & Stensgård, A. 2016. Food waste in Norway 2010–2015 – Final report from the ForMat Project. Østfoldforskning. [also available at <https://www.ostfoldforskning.no/no/publikasjoner/Publication/?id=2011>].
51. Hodges, R.J., Buzby, J.C. & Bennett, B. 2011. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *The Journal of Agricultural Science*, 149(S1): 37–45.
52. WRAP UK. 2017. *Household food waste in the UK, 2015*. Final report. Research date: September–October 2016 edition. Banbury, UK.
53. WRAP. 2013. *Household food and drink waste in UK*. Banbury, UK.
54. HISPACOOP. 2012. Estudio sobre el desperdicio de alimentos en los hogares. Confederación Española de Cooperativas de Consumidores y Usuarios (HISPACOOP).
55. Baptista, P., Campos, I., Pires, I. & Sofia, G. 2012. *Do campo ao garfo. Desperdício alimentar em Portugal*. Lisbon, Cestras.
56. Evans, D. 2011. Blaming the consumer – once again: the social and material contexts of everyday food waste practices in some English households. *Critical Public Health*, 21(4): 429–440.
57. Evans, D. 2012. Beyond the throwaway society: ordinary domestic practice and a sociological approach to household food waste. *Sociology*, 46(1): 41–56.
58. Quedsted, T., Marsh, E., Stunell, D. & Parry, A. 2013. Spaghetti soup: the complex world of food waste behaviours. *Resources, Conservation and Recycling*, 79: 43–51.
59. Soyeux, A. 2010. La lutte contre le gaspillage. Quel rôle face aux défis alimentaires? *Futuribles*, 362: 57–67.
60. Williams, H., Wikström, F., Otterbring, T., Löfgren, M. & Gustafsson, A. 2012. Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, 24: 141–148.
61. WRAP. 2008. *Research into consumer behaviour in relation to food dates and portion sizes*. Banbury, UK.
62. Esquerre, E.B., Del Carmen, D.R. & Rolle, R.S. 2017. Purchasing patterns and consumer level waste of fruits and vegetables in urban and peri-urban centers in the Philippines. *Food and Nutrition Sciences*, 08(10): 961–977.
63. Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., Silvennoinen, K., Waldron, K. & Vittuari, M. 2016. Food waste drivers in Europe, from identification to possible interventions. *Sustainability*, 9(1): 37.
64. WRAP. 2011. *Investigation into the possible impact of promotions on food waste*. Banbury, UK.
65. Stuart, T. 2009. *Waste: uncovering the global food scandal*. New York, USA, W.W. Norton & Company.
66. Cohen, J.F.W., Richardson, S., Austin, S.B., Economos, C.D. & Rimm, E.B. 2013. School lunch waste among middle school students. *American Journal of Preventive Medicine*, 44(2): 114–121.
67. Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. & Searchinger, T. 2013. *Reducing food loss and waste. Installment Two of 'Creating a sustainable food future'*. Working Paper. Washington, DC, World Resources Institute.
68. Edwardson, B. 2018. Status report on critical loss points and underlying causes of food losses in selected crop supply chains in developing countries. Draft. FAO.

69. FAO. 2016. *Food loss analysis: causes and solutions. Case studies in the small-scale agriculture and fisheries subsectors. Methodology*. Rome, Save Food: Global Initiative on Food Loss and Waste Reduction. (also available at www.fao.org/3/a-az568e.pdf).

70. Compton, J.A.F. & Sherington, J. 1999. Rapid assessment methods for stored maize cobs: weight losses due to insect pests. *Journal of Stored Products Research*, 35(1): 77–87.

71. GSARS. 2018. *Guidelines on the measurement of harvest and post-harvest losses recommendations on the design of a harvest and post-harvest loss statistics system for food grains (cereals and pulses)*. Rome, FAO.

72. FAO. 2019. *Questionnaire on Crop and Livestock Production and Utilization (2000–2017)*. Rome.

73. Reynolds, C., Goucher, L., Quedsted, T., Bromley, S., Gillick, S., Wells, V.K., Evans, D., Koh, L., Carlsson Kanyama, A., Katzeff, C., Svenfelt, Å. & Jackson, P. 2019. Review: Consumption-stage food waste reduction interventions – What works and how to design better interventions. *Food Policy*, 83: 7–27.

74. Lebersorger, S. & Schneider, F. 2011. Discussion on the methodology for determining food waste in household waste composition studies. *Waste Management*, 31(9): 1924–1933.

75. Hanssen, O. & Møller, H. 2013. *Food wastage in Norway 2013. Status and trends 2009–13. ForMat Project*.

76. FLW Protocol (Food Loss and Waste Protocol). 2016. *The food loss and waste accounting and reporting standard*. Washington, DC.

77. World Resources Institute. Forthcoming. *Reducing food loss and waste: getting across the tipping point*. Washington, DC, World Resources Institute.

CHAPTER 3

1. Hanson, C. & Mitchell, P. 2017. *The business case for reducing food loss and waste. A report on behalf of Champions 12.3*. Washington, DC, Champions 12.3.

2. Ellison, B., Muth, M.K. & Golan, E. 2019. Opportunities and challenges in conducting economic research on food loss and waste. *Applied Economic Perspectives and Policy*, 41(1): 1–19.

3. Quedsted, T., Marsh, E., Stunell, D. & Parry, A. 2013. Spaghetti soup: the complex world of food waste behaviours. *Resources, Conservation and Recycling*, 79: 43–51.

4. Anríquez, G., Foster, W., Santos-Rocha, J., Ortega, J. & Jansen, S. 2019. *Refining the definition of food loss and waste from an economic perspective: producers, intermediaries, and consumers as key*

decisionmakers. Santiago, Department of Agricultural Economics, Pontifical Catholic University of Chile.

5. Chegere, M.J. 2018. Post-harvest losses reduction by small-scale maize farmers: The role of handling practices. *Food Policy*, 77: 103–115.

6. Gromko, D. & Abdurasulova, G. 2018. *Climate change mitigation and food loss and waste reduction: exploring the business case*. Working Paper No. 246. Wageningen, The Netherlands, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

7. World Bank. 2011. *Missing food: the case of postharvest grain losses in Sub-Saharan Africa*. World Bank, Other Operational Studies 2824. Washington, DC. (also available at <https://ideas.repec.org/p/wbk/wboper/2824.html>).

8. FAO, IFAD & WFP. 2019. *Food loss analysis for identification of critical loss points and solutions of maize, sunflowers and beans value chains in Uganda*. Rome.

9. Bediako, J.A., Nkegbe, P. & Iddrisu, A. 2005. *Establishing the future potential for the use of mud silos by smallholder farmers: an assessment of mud silo promotion in the Northern Region of Ghana*. Tamale, Northern Region, Ghana, University of Development Studies.

10. ReFED. 2016. *A roadmap to reduce US food waste by 20 percent*. Berkeley, USA. (also available at <https://www2.deloitte.com/us/en/pages/operations/articles/refed-roadmap-to-reduce-us-food-waste.html>).

11. ICF. 2016. *Massachusetts Commercial Food Waste Ban Economic Impact Analysis*. Paper presented for the Massachusetts Department of Environmental Protection. Cambridge, USA.

12. WRAP. 2017. *Household food waste in the UK, 2015*. Final report. Research date: September–October 2016 edition. Banbury, UK.

13. Venkat, K. 2011. The climate change and economic impacts of food waste in the United States. *International Journal on Food System Dynamics*, 2(4): 431–446.

14. WRAP. 2013. *Household food and drink waste in the United Kingdom 2012*. Final report. Research date: May 2012–July 2013. Banbury, UK.

15. Rutten, M.M. & Kavallari, A. 2013. Can reductions in agricultural food losses avoid some of the trade-offs involved when safeguarding domestic food security? A case study of the Middle East and North Africa. Paper presented at 16th Annual Conference on Global Economic Analysis, June 2013, Shanghai, China.

16. Okawa, K. 2015. *Market and trade impacts of food loss and waste reduction*. OECD Food, Agriculture and Fisheries Papers 75. Paris, OECD.

REFERENCES

17. Rutten, M.M., Nowicki, P.L., Bogaardt, M.-J. & Aramyan, L.H. 2013. *Reducing food waste by households and in retail in the EU: a prioritisation using economic, land use and food security impacts*. IEI Report 2013-035. The Hague, IEI, Wageningen UR.
18. Fonseca, J. & Vergara, N. 2015. *Logistics in the horticulture supply chain in Latin America and the Caribbean. Regional report based on five country assessments and findings from regional workshops*. Rome, FAO.
19. FAO. 2011. *Global food losses and food waste – Extent, causes and prevention*. Rome.
20. Hodges, R.J., Buzby, J.C. & Bennett, B. 2011. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *The Journal of Agricultural Science*, 149(S1): 37–45.
21. WRAP. 2015. *Strategies to achieve economic and environmental gains by reducing food waste*. Banbury, UK.
22. WRAP. 2009. The economics of food waste. Unpublished conference paper prepared by Fathom Financial Consulting.
23. FAO. 2018. *Gender and food loss in sustainable food value chains – A guiding note*. Rome. [also available at <http://www.fao.org/3/i8620EN/i8620en.pdf>].
24. Delgado, L., Schuster, M. & Torero, M. 2019. Quantity and quality food losses across the value chain: a comparative analysis. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. Washington, DC, IFPRI. Unpublished.
25. FAO. 2018. *The Republic of Rwanda: maize, potato, tomato, milk. Food loss analysis: causes and solutions. Case studies in the small-scale agriculture and fisheries subsectors*. Rome.
26. Harvard Law School Food Law and Policy Clinic, Food Recovery Project & University of Arkansas. 2016. *Federal enhanced tax deduction for food donation: a legal guide*.
27. Shih-Hsun Hsu, T., Ching-Cheng, C. & Nguyen, T.T.T. 2018. *APEC survey report on feasible solutions for food loss and waste reduction*. Singapore, Asia-Pacific Economic Cooperation (APEC).
28. International Monetary Fund (IMF). 2016. *World Economic Outlook: Subdued demand – symptoms and remedies*. Washington, DC.
29. Barilla Center for Food & Nutrition. 2017. *Food Sustainability Index 2017. Global Executive Summary*. Parma, Italy.
30. FAO. 2015. The FTT-Thiaroye processing technique, an innovation for post-harvest loss reduction in fisheries and aquaculture. Paper presented at the First International Congress on Food Loss Prevention, 2015, Rome. [also available at www.fao.org/food-loss-reduction/news/detail/en/c/359611/].

CHAPTER 4

1. FAO, IFAD, UNICEF, WFP & WHO. 2017. *The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security*. Rome. [also available at <http://www.fao.org/3/a-i7695e.pdf>].
2. FAO, IFAD, UNICEF, WFP & WHO. 2018. *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition*. Rome. [also available at <http://www.fao.org/3/i9553en/i9553en.pdf>].
3. FAO, IFAD, UNICEF, WFP & WHO. 2019. *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns*. Rome.
4. Neff, R.A., Kanter, R. & Vandevijvere, S. 2015. Reducing food loss and waste while improving the public's health. *Health Affairs*, 34(11): 1821–1829.
5. Kummu, M., Fader, M., Gerten, D., Guillaume, J.H., Jalava, M., Jägermeyr, J., Pfister, S., Porkka, M., Siebert, S. & Varis, O. 2017. Bringing it all together: linking measures to secure nations' food supply. *Current Opinion in Environmental Sustainability*, 29: 98–117.
6. Shafiee-Jood, M. & Cai, X. 2016. Reducing food loss and waste to enhance food security and environmental sustainability. *Environmental Science & Technology*, 50(16): 8432–8443.
7. Candel, J. & Tielens, J. 2014. *Reducing food wastage, improving food security?* The Hague, Food & Business Knowledge Platform.
8. Affognon, H., Mutungi, C., Sanginga, P. & Borgemeister, C. 2015. Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis. *World Development*, 66: 49–68.
9. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2014. *Food losses and waste in the context of sustainable food systems*. Rome.
10. COMCEC Coordination Office. 2017. *Reducing food waste in the OIC countries*. Ankara, Standing Committee for Economic and Commercial Cooperation of the Organization of Islamic Cooperation (COMCEC).
11. Gaiani, S., Rezaei, M., Liu, B., Nana Heyl, J. & Bucatariu, C. forthcoming. Guiding principles for recovery and redistribution of safe and nutritious food for human consumption. Draft. FAO.
12. Global Panel on Agriculture and Food Systems for Nutrition (GLOPAN). 2018. *Preventing nutrient loss and waste across the food system: policy actions for high-quality diets*. Policy Brief No. 12. London.
13. Springmann, M. 2018. Global Panel on Agriculture and Food Systems for Nutrition (GLOPAN) background paper on the nutritional aspects of food loss and waste. Oxford, UK, University of Oxford.

14. World Bank. 2007. *World Development Report 2008. Agriculture for Development*. Washington, DC.
15. FAO. 2013. *The State of Food and Agriculture 2013. Food systems for better nutrition*. Rome. (also available at <http://www.fao.org/3/i3300e/i3300e.pdf>).
16. FAO. 2016. *Influencing food environments for healthy diets*. Rome. (also available at www.fao.org/3/a-i6484e.pdf).
17. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2016. *Sustainable agricultural development for food security and nutrition: what roles for livestock?* Rome.
18. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2017. *Sustainable forestry for food security and nutrition*. Rome.
19. Rutten, M.M. 2013. What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agriculture & Food Security*, 2(1): 13.
20. Chaboud, G. & Daviron, B. 2017. Food losses and waste: navigating the inconsistencies. *Global Food Security*, 12: 1–7.
21. Bahadur, K., Haque, I., Legwegoh, A. & Fraser, E. 2016. Strategies to reduce food loss in the global south. *Sustainability*, 8(7): 595.
22. Rosegrant, M., Magalhaes, E., Valmonte-Santos, R. & Mason-D'Croz, D. 2015. *Returns to investment in reducing postharvest food losses and increasing agricultural productivity growth – Post-2015 consensus*. Food Security and Nutrition Assessment Paper. Copenhagen Consensus Center.
23. Sheahan, M. & Barrett, C.B. 2017. Review: Food loss and waste in Sub-Saharan Africa. *Food Policy*, 70: 1–12.
24. African Union Commission. 2018. *Post-harvest loss management strategy*. Addis Ababa.
25. Conrad, Z., Niles, M.T., Neher, D.A., Roy, E.D., Tichenor, N.E. & Jahns, L. 2018. Relationship between food waste, diet quality, and environmental sustainability. *PLOS ONE*, 13(4): e0195405.
26. FAO. 2017. *Nutrition-sensitive agriculture and food systems in practice – options for intervention*. Rome. (also available at www.fao.org/3/a-i7848e.pdf).
27. Barbosa-Cánovas, G., Altunakar, B. & Mejía-Lorio, D. 2005. *Freezing of fruits and vegetables – an agri-business alternative for rural and semi-rural areas*. Agricultural Services Bulletin 158. Rome, FAO. (also available at <http://www.fao.org/3/y5979e/y5979e00.htm#Contents>).
28. Miller, D. & Welch, R. 2013. *Food system strategies for preventing micronutrient malnutrition*. ESA Working Paper No. 13-06. Rome, FAO. (also available at www.fao.org/3/CA2243EN/ca2243en.pdf).
29. Okawa, K. 2015. *Market and trade impacts of food loss and waste reduction*. OECD Food, Agriculture and Fisheries Papers 75. Paris, OECD.
30. Rutten, M., Verma, M., Mhlanga, N. & Bucatariu, C. 2015. *Potential impacts on sub-Saharan Africa of reducing food loss and waste in the European Union: a focus on food prices and price transmission effects*. Rome, FAO & LEI Wageningen UR.
31. Rutten, M.M., Nowicki, P.L., Bogaardt, M.-J. & Aramyan, L.H. 2013. *Reducing food waste by households and in retail in the EU: a prioritisation using economic, land use and food security impacts*. LEI Report 2013-035. The Hague, LEI, Wageningen UR.
32. Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P.M., Shiferaw, B. & Banziger, M. 2011. The metal silo: an effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Protection*, 30(3): 240–245.
33. Gitonga, Z., De Groote, H. & Tefera, T. 2015. Metal silo grain storage technology and household food security in Kenya. *Journal of Development and Agricultural Economics*, 7(6): 222–230.
34. Massachusetts Institute of Technology, The Comprehensive Initiative on Technology Evaluation (CITE). 2016. *Scaling adoption of hermetic post-harvest storage technologies in Uganda*. Full report. Cambridge, USA.
35. Tanager International. 2018. *AgResults Kenya On-Farm Storage Challenge Project – Summary Report*. Kenya.
36. FAO. 2018. *Food loss and waste and the right to adequate food: making the connection*. Rome.
37. WRAP. 2018. *Surplus food redistribution in the UK; 2015 to 2017*. Banbury, UK.
38. Berkenkamp, J. & Phillips, C. 2017. *Modeling the potential to increase food rescue: Denver, New York City and Nashville*. No. R-17-09-B. New York City, USA, Natural Resources Defense Council.
39. Daily Table. 2019. *FAQs* [online]. [Cited 9 January 2019]. <https://dailytable.org/faqs/>
40. Daily Table. 2019. *Daily Table SNAP Challenge* [online]. [Cited 9 January 2019]. <https://dailytable.org/snap/>
41. Adams, S. 2017. How Daily Table sells healthy food to the poor at junk food prices. *Forbes* [online]. [Cited 9 January 2019]. <https://www.forbes.com/sites/forbestreptalks/2017/04/26/how-daily-table-sells-healthy-food-to-the-poor-at-junk-food-prices/>
42. Mesa Brasil SESC. 2017. *Resultados – 2017/janeiro a maio* [online]. [Cited 15 April 2019]. <http://www.sesc.com.br/mesabrasil/resultados.html>

REFERENCES

43. **Egyptian FoodBank.** 2016. Experience and achievements. In: *Egyptian FoodBank* [online]. [Cited 17 April 2019]. <https://www.egyptianfoodbank.com/en/experience-and-achievements>
44. **FAO.** forthcoming. *Food recovery and redistribution: a practical guide for favourable policies and legal frameworks in Europe and Central Asia*. Draft working document. Budapest, Hungary, Save Food: Global Initiative on Food Loss and Waste Reduction and FAO.
45. **Blondin, S.A., Cash, S.B., Goldberg, J.P., Griffin, T.S. & Economos, C.D.** 2017. Nutritional, economic, and environmental costs of milk waste in a classroom school breakfast program. *American Journal of Public Health*, 107(4): 590–592.
46. **Ritchie, H., Reay, D.S. & Higgins, P.** 2018. Beyond calories: a holistic assessment of the global food system. *Frontiers in Sustainable Food Systems*, 2: 57.
47. **Lee, W.T.K., Tung, J.Y.A. & Paratore, G.** 2019. *Evaluation of micronutrient losses from postharvest food losses (PHL) in Kenya, Cameroon and India – implications on micronutrient deficiencies in children under 5 years of age*. Rome, FAO.
48. **Katona, P. & Katona-Apte, J.** 2008. The interaction between nutrition and infection. *Clinical Infectious Diseases*, 46(10): 1582–1588.
49. **Bourke, C.D., Berkley, J.A. & Prendergast, A.J.** 2016. Immune dysfunction as a cause and consequence of malnutrition. *Trends in Immunology*, 37(6): 386–398.
50. **Syed, S., Ali, A. & Duggan, C.** 2016. Environmental enteric dysfunction in children: a review. *Journal of Pediatric Gastroenterology and Nutrition*, 63(1): 6–14.
51. **WHO.** 2018. Micronutrient deficiencies – vitamin A deficiency. In: *Nutrition* [online]. [Cited 10 January 2019]. <https://www.who.int/nutrition/topics/vad/en/>.
52. **FAO.** 2016. *The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all*. Rome.
53. **Husein, Y., Secci, G., Dinnella, C., Parisi, G., Fusi, R., Monteleone, E. & Zanoni, B.** 2019. Enhanced utilisation of nonmarketable fish: physical, nutritional and sensory properties of ‘clean label’ fish burgers. *International Journal of Food Science & Technology*, 54(3): 593–601.
54. **East African Community.** 2017. *Disposal and alternative use of aflatoxin contaminated food*. Policy Brief No. 9.
55. **Smith, L.E., Prendergast, A.J., Turner, P.C., Mbuya, M.N.N., Mutasa, K., Kembo, G. & Stoltzfus, R.J.** 2015. The potential role of mycotoxins as a contributor to stunting in the SHINE trial. *Clinical Infectious Diseases*, 61(S7): S733–S737.
56. **Hoffmann, V., Jones, K. & Leroy, J.** 2015. Mitigating aflatoxin exposure to improve child growth in Eastern Kenya: study protocol for a randomized controlled trial. *Trials*, 16(1): 552.
57. **Hoffmann, V., Jones, K. & Leroy, J.L.** 2018. The impact of reducing dietary aflatoxin exposure on child linear growth: a cluster randomised controlled trial in Kenya. *BMJ Global Health*, 3(6): e000983.
58. **Hasib, N.I.** 2015. FAO expert tells Bangladesh formalin in food is not a health hazard. In: *bdnews24.com* [online]. [Cited 31 January 2019]. <http://bdnews24.com/health/2015/03/30/fao-expert-tells-bangladesh-formalin-in-food-is-not-a-health-hazard>
59. **Hoffmann, V. & Moser, C.** 2017. You get what you pay for: the link between price and food safety in Kenya. *Agricultural Economics*, 48(4): 449–458.
60. **WHO.** 2018. *Aflatoxins*. Food Safety Digest No. WHO/NHM/FOS/RAM/18.1. World Health Organization (WHO) Department of Food Safety and Zoonoses.
61. **Leroy, J.L., Wang, J.-S. & Jones, K.** 2015. Serum aflatoxin B1-lysine adduct level in adult women from Eastern Province in Kenya depends on household socio-economic status: a cross sectional study. *Social Science & Medicine*, 146: 104–110.
62. **De Groote, H., Kimenju, S.C., Likhayo, P., Kanampiu, F., Tefera, T. & Hellin, J.** 2013. Effectiveness of hermetic systems in controlling maize storage pests in Kenya. *Journal of Stored Products Research*, 53: 27–36.
63. **Williams, S.B., Baributsa, D. & Woloshuk, C.** 2014. Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination. *Journal of Stored Products Research*, 59: 190–196.
64. **Wahed, P., Razzaq, M.A., Dharmapuri, S. & Corrales, M.** 2016. Determination of formaldehyde in food and feed by an in-house validated HPLC method. *Food Chemistry*, 202: 476–483.
65. **FAO.** 2018. *Gender and food loss in sustainable food value chains – A guiding note*. Rome. (also available at <http://www.fao.org/3/i8620EN/i8620en.pdf>).
66. **Petros, S., Abay, F., Desta, G. & O'Brien, C.** 2018. Women Farmers' (dis)empowerment compared to men farmers in Ethiopia. *World Medical & Health Policy*, 10(3): 220–245.
67. **USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project.** 2014. *Understanding the women's empowerment pathway*. Improving Nutrition through Agriculture Technical Brief Series No. 4. Arlington, USA.
68. **Malapit, H.J.L. & Quisumbing, A.R.** 2015. What dimensions of women's empowerment in agriculture matter for nutrition in Ghana? *Food Policy*, 52: 54–63.

69. Cunningham, K., Ploubidis, G.B., Menon, P., Ruel, M., Kadiyala, S., Uauy, R. & Ferguson, E. 2015. Women's empowerment in agriculture and child nutritional status in rural Nepal. *Public Health Nutrition*, 18(17): 3134–3145.

70. Ruel, M.T. & Alderman, H. 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *The Lancet*, 382(9891): 536–551.

71. FAO. 2013. *Toolkit: reducing the food wastage footprint*. Rome.

72. Kuiper, M. & Cui, H.D. 2019. Using food loss reductions to reach nutritional and environmental objectives – a search for promising leverage points. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. The Hague, Wageningen Economic Research.

73. Beal, T., Massiot, E., Arsenault, J.E., Smith, M.R. & Hijmans, R.J. 2017. Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLOS ONE*, 12(4): e0175554.

74. FAO. 2019. Crop Market. In: *Family Farming Knowledge Platform* [online]. [Cited 16 May 2019]. <http://www.fao.org/family-farming/data-sources/dataportrait/crop-market/en/>

75. The Economist Intelligence Unit (EIU). 2014. *Food loss and its intersection with food security*. Global food security index 2014: Special report. London, The Economist.

76. Barrett, C. 2015. *Benefits and costs of the food security and nutrition targets for the post-2015 development agenda*. Copenhagen Consensus Center Food Security and Nutrition Perspective Paper.

CHAPTER 5

1. FAO. 2013. *Food Wastage Footprint: Impacts on Natural Resources – Summary Report*. Rome.

2. FAO. 2018. The future of food and agriculture. Alternative pathways to 2050. Rome.

3. Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P.J. 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, 438: 477–489.

4. FAO. 2011. Global food losses and food waste – Extent, causes and prevention. Rome.

5. Gustavsson, J., Cederberg, C., Sonesson, U. & Emanuelsson, A. 2013. The methodology of the FAO study: “Global food losses and food waste – extent, causes and prevention”. FAO, 2011. SIK report No. 857. Lund, Sweden, Swedish Institute for Food and Biotechnology (SIK).

6. FAO. 2016. Water withdrawal by sector, around 2010. In: AQUASTAT database [online]. www.fao.org/nr/water/aquastat/tables/WorldData-Withdrawal_eng.pdf

7. Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J. & Willett, W. 2018. Options for keeping the food system within environmental limits. *Nature*, 562(7728): 519–525.

8. FAO. 2013. *Toolkit: reducing the food wastage footprint*. Rome.

9. Wunderlich, S.M. & Martinez, N.M. 2018. Conserving natural resources through food loss reduction: Production and consumption stages of the food supply chain. *International Soil and Water Conservation Research*, 6(4): 331–339.

10. de Ruiter, H., Macdiarmid, J.I., Matthews, R.B., Kastner, T., Lynd, L.R. & Smith, P. 2017. Total global agricultural land footprint associated with UK food supply 1986–2011. *Global Environmental Change*, 43: 72–81.

11. Chapagain, A. & James, K. 2011. *The water and carbon footprint of household food and drink waste in the UK*. Edinburgh, UK, World Wildlife Fund.

12. FAO. 2018. Online statistical database. In: FAOSTAT [online]. <http://faostat.fao.org>

13. Mekonnen, M. & Hoekstra, A.Y. 2010. *The green, blue and grey water footprint of animals and animal products*. Delft, Netherlands, UNESCO-IHE Institute for Water Education. (also available at <https://research.utwente.nl/en/publications/the-green-blue-and-grey-water-footprint-of-animals-and-animal-prod>).

14. FAO. 2019. *Food Loss Index. Online statistical working system for loss calculations* (available at <http://www.fao.org/food-loss-and-food-waste/flw-data>).

15. Mekonnen, M.M. & Hoekstra, A.Y. 2011. The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences Discussions*, 8(1): 763–809.

16. Westhoek, H., Rood, T., van den Berg, M., Janse, J., Nijdam, D., Reudink, M., Stehfest, E., Lesschen, J.P., Oenema, O. & Woltjer, G.B. 2011. The protein puzzle: the consumption and production of meat, dairy and fish in the European Union. No. 500166001. The Hague, Netherlands Environmental Assessment Agency. (also available at <http://library.wur.nl/WebQuery/wurpubs/406619>).

17. Kuiper, M. & Cui, H.D. 2019. Using food loss reductions to reach nutritional and environmental objectives – a search for promising leverage points. Background paper for *The State of Food and Agriculture 2019. Moving forward on food loss and waste*. The Hague, Wageningen Economic Research.

REFERENCES

18. Kummu, M., Fader, M., Gerten, D., Guillaume, J.H., Jalava, M., Jägermeyr, J., Pfister, S., Porkka, M., Siebert, S. & Varis, O. 2017. Bringing it all together: linking measures to secure nations' food supply. *Current Opinion in Environmental Sustainability*, 29: 98–117.
19. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath Reddy, K., Narain, S., Nishtar, S. & Murray, C.J.L. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393(10170): 447–492.
20. FAO. 2016. *The State of Food and Agriculture 2016. Climate change, agriculture and food security*. Rome.
21. Ridoutt, B.G., Juliano, P., Sanguansri, P. & Sellaheewa, J. 2010. The water footprint of food waste: case study of fresh mango in Australia. *Journal of Cleaner Production*, 18(16): 1714–1721.
22. James, S.J. & James, C. 2010. The food cold-chain and climate change. *Food Research International*, 43(7): 1944–1956.
23. International Institute of Refrigeration. 2009. *The role of refrigeration in worldwide nutrition – 5th informative note on refrigeration and food*. Paris.
24. International Institute of Refrigeration. 2002. *Report on refrigeration sector achievements and challenges*. Paris.
25. IPCC & UNEP. 2005. *IPCC/TEAP special report on safeguarding the ozone layer and the global climate system: issues related to hydrofluorocarbons and perfluorocarbons*. Cambridge.
26. FAO & GIZ. 2019. *Measuring Impacts and Enabling Investments in Energy-smart Agrifood Chains. Findings from four country studies*. Rome, FAO.
27. Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. & Searchinger, T. 2013. Reducing food loss and waste. Installment Two of 'Creating a sustainable food future'. Working Paper. Washington, DC, World Resources Institute.
28. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2014. *Food losses and waste in the context of sustainable food systems*. Rome.
29. Geyer, R., Jambeck, J.R. & Law, K.L. 2017. Production, use, and fate of all plastics ever made. *Science Advances*, 3(7): e1700782.
30. Schönrock, D. 2008. *Hochkonjunktur für Schweizer Verpackungen*. Pack Aktuell.
31. Licciardello, F. 2017. Packaging, blessing in disguise. Review on its diverse contribution to food sustainability. *Trends in Food Science & Technology*, 65: 32–39.
32. Heller, M.C., Selke, S.E.M. & Keoleian, G.A. 2019. Mapping the influence of food waste in food packaging environmental performance assessments. *Journal of Industrial Ecology*, 23(2): 480–495.
33. Wikström, F. & Williams, H. 2010. Potential environmental gains from reducing food losses through development of new packaging – a life-cycle model. *Packaging Technology and Science*, 23(7): 403–411.
34. Hellström, D. & Olsson, A. 2016. *Managing packaging design for sustainable development*. John Wiley & Sons, Ltd. (also available at <https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119151036.fmatterl>).
35. Wikström, F., Verghese, K., Auras, R., Olsson, A., Williams, H., Wever, R., Grönman, K., Kvalvåg Pettersen, M., Møller, H. & Soukka, R. 2018. Packaging strategies that save food: a research agenda for 2030. *Journal of Industrial Ecology*, 23(3): 532–540.
36. Marsh, K. & Bugusu, B. 2007. Food packaging – roles, materials, and environmental issues. *Journal of Food Science*, 72(3): R39–R55.
37. CDKN. 2014. The IPCCs Fifth Assessment Report – What's in it for Africa? In: *Climate and Development Knowledge Network* [online]. [Cited 21 March 2019]. <https://cdkn.org/resource/highlights-africa-ar5/>
38. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2012. *Food security and climate change*. Rome.
39. IPCC. 2015. Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Climate Change, Food, and Agriculture. M.D. Mastrandrea, K.J. Mach, V.R. Barros, T.E. Bilir, D.J. Dokken, O. Edenhofer, C.B. Field, T. Hiraishi, S. Kadner & T. Krug, eds. Geneva, Switzerland, World Meteorological Organization.

CHAPTER 6

1. High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE). 2014. *Food losses and waste in the context of sustainable food systems*. Rome.
2. Hanson, C. & Mitchell, P. 2017. *The business case for reducing food loss and waste. A report on behalf of Champions 12.3*. Washington, DC, Champions 12.3.
3. FAO. 2014. *The State of Food and Agriculture 2014. Innovation in family farming*. Rome.
4. FAO. 2016. *The State of Food and Agriculture 2016. Climate change, agriculture and food security*. Rome.

5. Lundqvist, J., de Fraiture, C. & Molden, D. 2008. *Saving water: from field to fork. Curbing losses and wastage in the food chain*. SIWI Policy Brief. Stockholm, Stockholm International Water Institute (SIWI). [also available at <http://hdl.handle.net/10535/5088>].
6. World Bank. 2017. *Mexico – Grain Storage and Information for Agricultural Competitiveness Project*. (English). Washington, D.C.
7. World Bank. 2018. Information Statement: International Bank for Reconstruction and Development. In: *The World Bank* [online]. [Cited 1 June 2019]. www.worldbank.org/en/who-we-are/ibrd
8. Miroso, M., Yip, R. & Lentz, G. 2018. Content analysis of the 'Clean Your Plate Campaign' on Sina Weibo. *Journal of Food Products Marketing*, 24(5): 539–562.
9. FAO & CIHEAM. 2016. *Mediterra 2016. Zero Waste in the Mediterranean. Natural Resources, Food and Knowledge*. Paris, Presses de Sciences Po.
10. Turkish Grain Board (TMO). 2014. The meeting held for the announcement of the results of the Campaign for Preventing Bread Waste. In: *TMO* [online]. [Cited 1 April 2019]. <http://www.tmo.gov.tr/Main.aspx?ID=1045>
11. Ajde Makedonija. 2019. Ajde Makedonija – History. In: *Ajde Makedonija* [online]. [Cited 13 June 2019]. <http://ajdemakedonija.mk/history/>
12. FAO. forthcoming. Food recovery and redistribution: a practical guide for favourable policies and legal frameworks in Europe and Central Asia. Draft working document. Budapest, Hungary, Save Food: Global Initiative on Food Loss and Waste Reduction and FAO.
13. Ajde Makedonija. 2019. *Food Waste Experiential Learning Program – Ajde Makedonija* [online]. [Cited 13 June 2019]. <http://ajdemakedonija.mk/campaign/food-waste-experiential-learning-program/>
14. FUSIONS. 2015. *Food waste in Denmark reduced by 25% and 4,4 billion DKK* [online]. [Cited 2 May 2019]. <https://www.eu-fusions.org/index.php/about-fusions/news-archives/238-food-waste-in-denmark-reduced-by-25-and-4-4-billion-dkk>
15. Halloran, A., Clement, J., Kornum, N., Bucatariu, C. & Magid, J. 2014. Addressing food waste reduction in Denmark. *Food Policy*, 49: 294–301.
16. Kulikovskaja, V. & Aschemann-Witzel, J. 2017. Food waste avoidance actions in food retailing: the case of Denmark. *Journal of International Food & Agribusiness Marketing*, 29(4): 328–345.
17. Kulikovskaja, V. & Aschemann-Witzel, J. 2016. *Food waste avoidance initiatives in Danish food retail*. No. WP6.2 Report. Aarhus, Denmark, Aarhus University, Department of Management.
18. Capone, R., Bilali, H.E., Debs, P., Bottalico, F., Cardone, G., Berjan, S., Elmenofi, G.A.G., Abouabdillah, A., Charbel, L., Arous, S.A. & Sassi, K. 2016. Bread and bakery products waste in selected Mediterranean Arab countries. *American Journal of Food and Nutrition*, 4(2): 40–50.
19. AFED. 2015. *Arab Environment: Sustainable Consumption. Annual Report of Arab Forum for Environment and Development, 2015*; Abdel Gelil, I. and Saab, N. (Eds.); Beirut, Lebanon. Technical Publication.
20. World Bank. 2015. Building resilience and opportunity: social protection reform in Egypt. In: *The World Bank* [online]. [Cited 11 March 2019]. <http://www.worldbank.org/en/news/feature/2015/06/09/building-resilience-and-opportunity-social-protection-reform-in-egypt>
21. FAO. 2013. *Report of the Expert Consultation Meeting on Food Losses and Waste Reduction in the Near East Region. Towards a Regional Comprehensive Strategy*. Cairo.
22. Duwayri, M. 2016. Rethinking food subsidy in Jordan. In: *IFPRI* [online]
23. Khraishy, M. 2018. Jordan ends bread subsidies, implements USDA-style SNAP EBT program. No. JO18001. US Department of Agriculture, Economic Research Service.
24. FAO. 2019. *FAO GIEWS Country Brief on Jordan* [online]. [Cited 13 May 2019]. www.fao.org/giews/countrybrief/country.jsp?code=JOR
25. Conrad, Z., Niles, M.T., Neher, D.A., Roy, E.D., Tichenor, N.E. & Jahns, L. 2018. Relationship between food waste, diet quality, and environmental sustainability. *PLOS ONE*, 13(4): e0195405.
26. IMechE. 2014. *A tank of cold: Cleantech leapfrog to a more food secure world*. London, Institute of Mechanical Engineers.
27. Ambuko, J., Karithi, E., Hutchinson, M. & Owino, W. 2018. Modified atmosphere packaging enhances the effectiveness of Coolbot™ cold storage to preserve postharvest quality of mango fruits. *Journal of Food Research*, 7(5): 7.
28. FANRPAN. 2017. Cost benefit analysis of post-harvest management innovations in Mozambique. Pretoria.
29. FANRPAN. 2017. Cost benefit analysis of post-harvest management innovations. Benin case study report. Pretoria.
30. FAO. 2015. The FTT-Thiaroye processing technique, an innovation for post-harvest loss reduction in fisheries and aquaculture. Paper presented at the First International Congress on Food Loss Prevention, 2015, Rome. [also available at www.fao.org/food-loss-reduction/news/detail/en/c/359611/].
31. FAO & EBRD. 2016. *Morocco – adoption of climate technologies in the agrifood sector*. Country Highlights edition. Rome, FAO Investment Centre.

REFERENCES

32. **Apeel Sciences**. 2018. Science. In: *Apeel* [online]. [Cited 12 March 2019]. <https://apeelsciences.com/science/>
33. **Pellman Rowland, M.** 2017. Apeel's invisible coating could be a game-changer. In: *Forbes* [online]. [Cited 13 March 2019]. <https://www.forbes.com/sites/michaelpellmanrowland/2017/10/19/apeel-sustainable-fruit-veggies/>
34. **Simon, M.** 2018. The amphiphilic liquid coating that keeps your avocados fresh. *Wired* [online]. [Cited 11 March 2019]. <https://www.wired.com/story/apeel/>
35. **Wasteless**. 2018. Case studies – leading Spanish retailer cuts a third of its food waste using Wasteless Dynamic Pricing. In: *Wasteless* [online]. [Cited 31 January 2019]. <https://www.wasteless.co/case-studies>
36. **Kirchgaessner, S.** 2016. Italy tackles food waste with law encouraging firms to donate food. *The Guardian*, 3 August 2016. [also available at <https://www.theguardian.com/world/2016/aug/03/italy-food-waste-law-donate-food>].
37. **ACHIPIA**. 2017. *Comité intersectorial presenta plan de acción para la reducción de desperdicios de alimentos en Chile* [online]. [Cited 13 June 2019]. <https://www.achipia.gob.cl/2017/12/13/comite-intersectorial-presenta-plan-de-accion-para-la-reduccion-de-desperdicios-de-alimentos-en-chile/>
38. **Ministerio de Agroindustria**. 2017. *Valoremos los alimentos – Guía integral para municipios*. Government of Argentina.
39. **European Commission**. 2015. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop – An EU action plan for the Circular Economy. Brussels.
40. **European Commission**. 2016. Food Waste. In: *Commission and its priorities: Policies, information and services* [online]. [Cited 13 June 2019]. https://ec.europa.eu/food/safety/food_waste_en
41. **European Commission**. 2015. European Union Platform on Food Losses and Food Waste. Brussels. [also available at https://ec.europa.eu/food/safety/food_waste/eu_actions/eu-platform_en].
42. **European Commission**. 2017. European Union guidelines on food donation. Brussels.
43. **European Commission**. 2018. Guidelines for the feed use of food no longer intended for human consumption. Brussels. [also available at [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018XC0416\(01\)](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018XC0416(01))].
44. **European Commission**. 2018. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance). Brussels. [also available at <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018L0851>].
45. **European Commission**. 2019. Commission Delegated Decision (EU) .../... of 3.5.2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste. C(2019) 3211 final. Brussels.
46. **European Commission**. 2019. *Towards a sustainable Europe by 2030*. Reflection paper. COM(2019)22. Brussels.
47. **FAO**. 2018. *Gender and food loss in sustainable food value chains – A guiding note*. Rome. [also available at <http://www.fao.org/3/i8620EN/i8620en.pdf>].
48. **Fabi, C., English, A., Mingione, M. & Jona Lasinio, G.** 2018. SDG 12.3.1: Global Food Loss Index. Imputing Food Loss Percentages in the absence of data at the global level. Rome, FAO.
49. **GSARS**. 2018. *Guidelines on the measurement of harvest and post-harvest losses recommendations on the design of a harvest and post-harvest loss statistics system for food grains (cereals and pulses)*. Rome, FAO.
50. **FAO**. 2018. *Methodological proposal for monitoring SDG target 12.3: the Global Food Loss Index design, data collection methods and challenges*. Rome, FAO Statistical Division.
51. **Fonteneau, F.** 2017. The Agricultural Integrated Survey (AGRIS): rationale, methodology, implementation. ICAS VII 2016: *Seventh International Conference on Agriculture Statistics Proceedings*.
52. **FAO**. 2017. *World Programme for the Census of Agriculture 2020*. FAO Statistical Development Series No. 1. Rome.

TECHNICAL ANNEX

1. **FAO**. 2018. *Methodological proposal for monitoring SDG target 12.3: the Global Food Loss Index design, data collection methods and challenges*. Rome, FAO Statistical Division.
2. **FAO**. 2011. *Global food losses and food waste – Extent, causes and prevention*. Rome.
3. **Fabi, C., English, A., Mingione, M. & Jona Lasinio, G.** 2018. SDG 12.3.1: Global Food Loss Index. Imputing Food Loss Percentages in the absence of data at the global level. Rome, FAO.
4. **Global Strategy to improve Agricultural and Rural Statistics (GSARS)**. 2017. *Field test report on the estimation of crop yields and post-harvest losses in Ghana*. Technical Report no. 29. Global Strategy Technical Report. Rome.