Assessing trade-offs of interventions aiming at reducing food loss

Applying a food system perspective for better policy decisions

Siemen van Berkum and Ezra Berkhout

WAGENINGEN
UNIVERSITY & RESEARCH

Assessing trade-offs of interventions aiming at reducing food loss

Applying a food system perspective for better policy decisions

Siemen van Berkum and Ezra Berkhout

This study was carried out by Wageningen Economic Research and was commissioned and subsidised by the Dutch Ministry of Agriculture, Nature and Food Quality within the context of the 'Transition to climate smart and circular food systems' research theme of the Policy Support (project number BO-43-003-002)

Wageningen Economic Research
Wageningen, March 2022

REPORT
2022-039
ISBN 978-94-6447-159-5

WAGENINGEN
UNIVERSITY & RESEARCH

Siemen van Berkum and Ezra Berkhout, 2022. *Assessing trade-offs of interventions aiming at reducing food loss; Applying a food system perspective for better policy decisions.* Wageningen, Wageningen Economic Research, Report 2022-039. 36 pp.; 8 fig.; 2 tab.; 47 ref.

This report discusses impacts food loss reduction interventions may have, highlighting the potential trade-offs between food system objectives of improving food security and reducing environmental pressures. The report shows that food loss reduction can be an effective strategy that contributes to better food system outcomes, but not by default: detailed inquiry is needed to determine which measure to use where in the supply chain for the most effective leverage. The report concludes by presenting a decision-making scheme that may act as a guideline for an ex-ante evaluation of an intended food loss reduction intervention, and may help policy makers develop a national food loss reduction plan.

Keywords: food loss, food system, trade-offs, food security, sustainability, Dutch food security policy

This report can be downloaded for free at https://doi.org/10.18174/567258 or at www.wur.eu/economic-research (under Wageningen Economic Research publications).

P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30,
E communications.ssg@wur.nl, http://www.wur.eu/economic-research. Wageningen Economic Research is part of Wageningen University & Research.

Wageningen Economic Research Report 2022-039 | Project code 2282500451

Cover photo: Shutterstock

Contents

Preface

In tackling global challenges of producing sufficient healthy food for an increasing population the food system approach is increasingly used as a framework for seeking entry points for transformation towards a more sustainable, inclusive and resilient food system. Food system approaches increasingly consider a more holistic point of view beyond the value chain to include more (global) environmental and socio-economic drivers and food security outcomes.

The 2019 Dutch Government Food security policy note also takes the food system concept as key for addressing food security, and in achieving SDGs and the Paris Climate Agreement. According to the policy note, reducing food loss can be seen as an important instrument for strengthening both food security and ecologically sustainable production systems in low- and middle-income countries. This report contributes insights into how food loss reduction interventions may contribute to those objectives, highlights the potential trade-offs between the objectives and proposes a decision-scheme that can guide policy makers in ex-ante evaluations of proposals for food loss reduction interventions.

This study was commissioned and financed by the Dutch Ministry of Agriculture, Nature and Food Quality (LNV). The study was directed by Hans Brand, Jeanet Smid-Goosen (EAI, LNV), Vera Musch (SK&I, LNV) and Jan Verhagen (Wageningen UR). We would like to thank the Steering Committee for the constructive collaboration and for their valuable comments and suggestions on the final draft version of this report. We give special thanks for the pleasant and helpful way in which they have guided the research. Many thanks also go to Heike Axmann and Han Soethoudt (Wageningen Food and Biobased Research) who provided valuable comments on draft report versions.

Prof.dr.ir. J.G.A.J. (Jack) van der Vorst
Managing Director Social Sciences Group (SSG)
Wageningen University & Research

Executive summary

ES.1 Key messages

Food loss (FL) reduction is often assumed to enhance food security and reduce the environmental footprint of food production. This report concludes that implementing FL-reduction interventions can be an effective strategy that contributes to better food system outcomes, but not by default: detailed inquiry is needed to determine which measure to use where in the supply chain for the most effective leverage. When applied, there can be winners and losers, that is, actors that benefit from the intervention and those that do not gain. Moreover, there may be important trade-offs of FL interventions between food security and environmentally sustainable production objectives.

Added to this, evidence shows that other targeted policies and investments than FL-reduction interventions – for instance, investments in agricultural R&D, agricultural extension services and digital agricultural information systems, – may be better suited to address food insecurity and unsustainable production.

Research into promising valorisation pathways of residues is mainly technical in nature, with little economic assessments reflecting local context. Studies simultaneously weighing economic, social and environmental impacts of residual biomass valorisation are missing.

ES.2 Other findings

An intervention that reduces loss has a market effect: smaller loss means more supply with the same means of production, causing prices to fall. Consumers/users benefit as they pay a lower price, but suppliers' (farmers/processors) revenues decline, certainly in the short term as they reduce their supply; in the somewhat longer term, suppliers may be able to respond to growing demand (driven by lower prices and/or income increase). The way in which the market responds to the FL intervention depends on price elasticities of supply and demand; these differ per product and country/income level. Moreover, the effectiveness of reducing FL in generating desirable food security and environmental outcomes depends on how an intervention affects prices across commodities and locations, and along supply chains.

Literature review shows studies evaluating impacts of innovations aiming at food loss reduction mainly focus on investments in storage facilities. In majority, these studies have been conducted under controlled settings (laboratory, test fields) with little participation from farmers or other community members, leaving the effectiveness of the intervention in real life and the possible adoption rate by farmers an open question. In many parts of Sub-Saharan Africa, improved crop storage bags (such as PICS bags) are increasingly being used, showing positive financial results of investing in these bags. However, evaluating studies are for specific crops, in specific countries only, while studies on the breadth and depth of adoption, as well as aggregate effects on prices, food security or environmental effects (i.e. the overall reductions in pesticide use) are lacking.

Results from integrated simulation models show reducing food loss can have positive food security and environmental effects, especially for low-income countries, but results are based on costless interventions and do not take into account technical change related complementary adoption and adaptation pathways, in particular how social and economic barriers hamper the diffusion of innovations, especially among small (economically vulnerable) farmers.

When pursuing environmental objectives (GHG reduction, preserving land, increase water quality) by reducing food loss, impacts are conditioned by market responses (that is, supply and demand elasticities), and the correspondence of the stage in the supply chain at which the environmental burden largely occurs and where the intervention is implemented. In the absence of market response information and food loss data in each of the supply chain segments, a heuristic approach can serve to identify situations where FL interventions are most likely to have positive environmental outcomes.

ES.3 A decision-making scheme to guide policy action

Such a heuristic is presented in a decision-making scheme that asks key questions about where the greatest loss in the supply chain occur, how consumers and producers can be expected to respond to prices, and what the costs of intervention are (see ES Figure 1). Depending on the objective being pursued (food security/produce more with less resources, or relieve environmental pressure) a first ex-ante assessment of a specific project proposal to reduce food loss can be made.

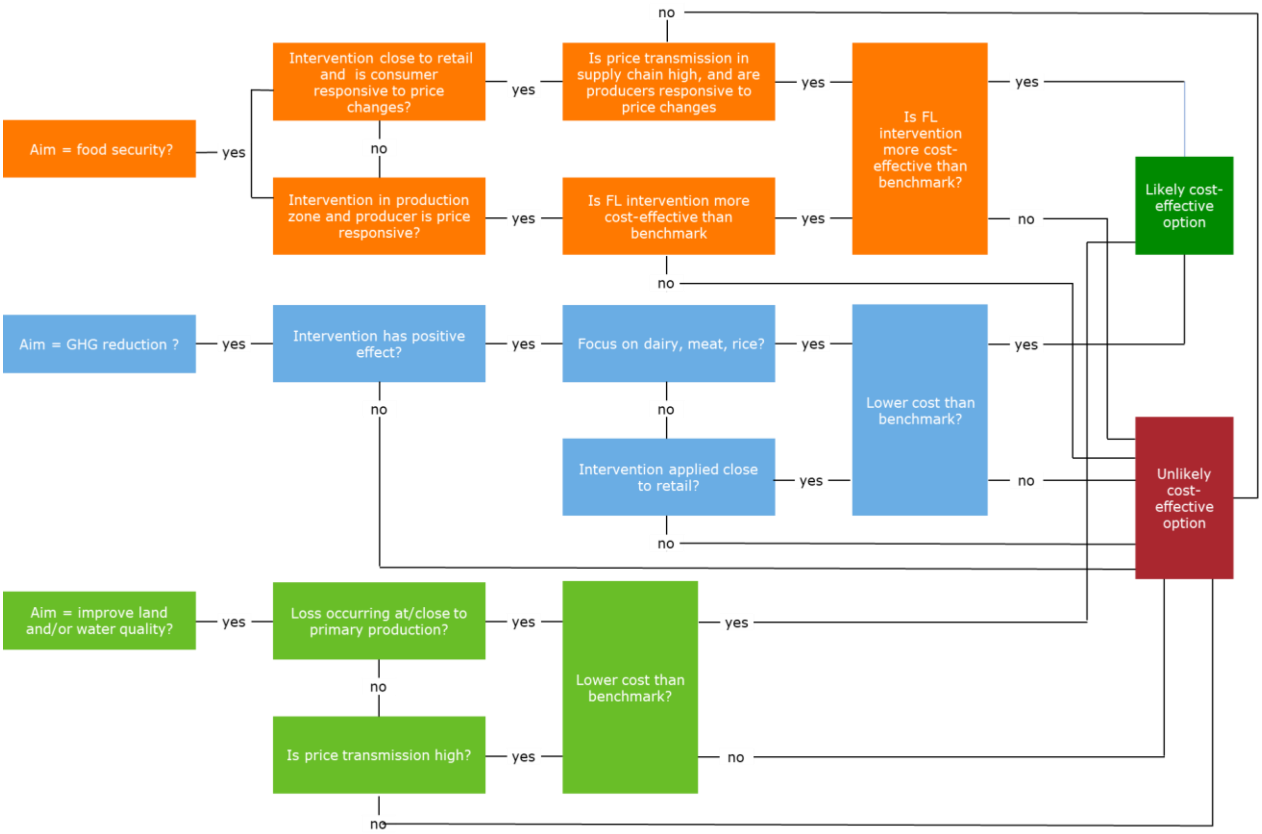

Figure ES.1 *Decision-tree for uncovering whether a food loss (FL) reduction proposition contributes to food security and environmental policy goals cost-effectively (See Appendix Table A1 for further clarification)*

Also, questions about causes and main locations of loss, and the main supply/demand characteristics of the commodities with highest losses can be treated as generic steps at the country level where their answers can feed into a 'national food loss policy plan'. Such a comprehensive policy plan ideally combines insights on both technical options to reduce FL in commodity chains, as well as ex-ante insights on equilibrium effects on economies and societal indicators. On the basis of such a national policy plan, suggestions can be made to local (or regional) authorities and other stakeholders in the relevant supply chains for projects to reduce loss, while also indicating how support from the Dutch private sector and/or knowledge institutions can be obtained.

1 Introduction

1.1 Research motivation

A significant share of agricultural production does not reach the consumers' plate (e.g. FAO, 2019; Lipinski et al., 2013) or is wasted (e.g. Fusions, 2016), even though precise estimates of the shares of production lost remain scarce. Nonetheless, the existence of Food Loss and Waste (FLW) implies that natural resources and inputs are spoiled and nutritious foods remain unused. Based on these premises, the reduction of FLW has gained widespread momentum in policy circles during the past decade (e.g. UNFCCC, UNEP) as a means to enhance food availability for the poor and vulnerable, as well as to reduce the environmental footprint of the agricultural sector. This policy focus on FLW has further culminated in the inclusion of FLW in the Sustainable Development Goals (SDGs), making reductions a global concern, with targets to halve per capita global food waste at the retail and consumer levels and reduce food loss along production and supply chains, including post-harvest loss by 2030 (UN, 2019, SDG12.3).

Within the SDGs, FLW reduction serves a larger goal of responsible consumption and production (SDG 12) for achieving development goals while reducing economic, environmental and social costs. Interventions aimed at reducing food loss should therefore be assessed on their contribution to food security, efficiency, inclusiveness (distribution effects) and reducing environmental pressure. FLW reduction interventions can potentially be a means to enhance food security, through greater supply at lower prices to consumers,[1] to enhance land and water resource efficiency or reduce greenhouse gas emissions. Seen from this point of view, reducing FLW is not an objective in itself but a means to achieve such policy objectives. Understanding the relative contribution of FLW in achieving a specific goal, like greater food security, also allows for comparing the effectiveness of FLW with alternative policy interventions. This begs the question as to whether policy interventions to reduce FLW serve to achieve these goals simultaneously, always and everywhere, or whether trade-offs between these goals may arise.

This study relies on a food systems approach to investigate these questions in greater detail, with a particular focus on interventions aimed at reducing FL – that is, loss of food occurring on the farm, trade and logistics, and processing level up to the retail where food is sold to consumers and end consumers. A systems approach is thereby particularly well suited to reveal if and where trade-offs between policy goals may arise, under which conditions and if and how these can be mitigated. For instance, studies suggest that reducing post-harvest loss is an important strategy for improved resource efficiency, enhanced food security and reduced environmental impacts (HLPE, 2014; WRI, 2018; EAT-Lancet, 2019; FAO, 2019). However, the impacts of FL reduction on food security or the environment remain ambiguous (Rutten, 2013) and are conditional on stakeholder relationships, market characteristics, where interventions occur along the supply chain[2] and local context (Lipinsky et al., 2013; HLPE, 2014; Sheahan and Barrett, 2017; FAO, 2019). In addition, post-harvest loss interventions appear to be a relatively cost-inefficient approach for combating food insecurity (Chichaibelu et al., 2021).

---

1 The rationale behind the assumption that FLW reduction improves food security is that food access and affordability improve as more food will be available at lower prices. However, the relationships between these three dimensions of food security are not clear-cut. For example, more food available at lower prices may improve its affordability but whether poor, food insecure households actually will have improved access to cheaper food also depends on location-specific factors, such the vicinity to shops/vendors selling cheaper foods. In addition, as is explained in more detail in Chapter 2, farmers receiving lower prices may lose income when FLW decline, whereas traders or processors may increase their margins. Hence, the claim that FLW reduction improves food security needs further clarification, because food security has different dimensions, with complex relationships between these dimensions, resulting in potentially different distributional effects of FLW reduction interventions among actors in the supply chain, and between producers and consumers (as further explained in Chapter 2).

2 Studies describing interventions to reduce FL often use the terms supply chain and value chain interchangeably. While *supply chain* captures the physical process of moving goods, including storage and transport, *value chain* focuses on the process of adding value by different actors along the chain. Food loss can emerge in both types of processes. Without loss of generality this study uses the term *supply chain*.

Moreover, the environmental impacts of reducing FL interventions may be negligible or even negative when the financial savings from FL lead to increases of more environmentally damaging consumption of goods outside of the food system (e.g. Catteneo et al., 2021).

Equally important is to consider the, potentially varying, impact on diverse groups of stakeholders of policy interventions to reduce FL. A global perspective on FL reductions suggests improvements in both food security and the environment – if less food gets lost, less needs to be produced to improve global food security thus also reducing environmental impacts. However, the existence of current levels of FL could also be interpreted as an economically efficient outcome across diverse actors in the current system. Interventions to reduce FL may tilt the balance, with costs for reducing FL outweighing financial gains, creating winners and losers throughout the food system (e.g. Kuiper and Cui, 2021). When the latter are not compensated, they have no incentive to either prevent or reduce FL.

In short, policy interventions aimed at reducing FL may lead to envisaged environmental or socioeconomic policy objectives, but not automatically as impacts depend on many factors. With a focus on low and middle-income countries (LMICs), this study therefore explores potential trade-offs emerging from interventions aimed at reducing FL occurring on the farm, trade and logistics, and processing level up to the retail where food is sold to consumers and end-consumers.

1.2 Key question, approach and report structure

This study reviews literature showing impacts of interventions aiming at reducing FL using a food system perspective, that is, in addition to food and nutrition security effects, also economic (livelihoods), social (inclusion) and environmental impacts are addressed. The main research question is:

what are trade-offs of food loss (FL) reduction interventions in the supply chain in terms of economic/social/environmental and food and nutrition security impacts and objectives?

In the elaboration of this question, we pay attention to issues of measurement of FL, its causes and suggested strategies to prevent FL and we review the benefits and costs of interventions aiming at reducing loss. Also, we examine how interventions downstream will affect upstream parts of the supply chain and the potential trade-offs between food policy objectives of specific FL reducing or preventing interventions in a LMIC context. This translates into a report structure in which Chapter 2 outlines recent estimates of FL and shows where in the food supply chain, and for which (groups of) commodities, the highest loss occurs, according to FAO sources. Next, the chapter explains major conceptual frameworks used in literature that help understand the expected impacts of interventions targeted at reducing FL. Chapter 3 is a deep dive into the currently available literature on evidence: it highlights the main proposed and/or adopted strategies to reduce FL and discusses their (expected) impacts on food system outcomes. Chapter 4 briefly summarises main findings and messages from the literature review, followed by a decision-making tool that can be used for uncovering whether a FL-reduction proposition contributes to food security and/or environmental goals cost-effectively.

The methodology of the study is a comprehensive literature review of secondary data and existing evidence on the impacts of food/post-harvest loss interventions in the context of food system outcomes. The literature considered relevant to be reviewed for the purpose of this report is scientific articles and research reports that have been selected on the basis of (different combinations of) the keywords 'food loss', 'food system', 'trade-off', 'food security', 'sustainability'. In addition, selected literature had to be studies addressing FL-reduction interventions in low and middle-income countries. For Section 3.5 (on valorisation of agricultural residues), an additional literature search has been conducted, with specific keywords used (see Section 3.5, footnote 13).

2 Understanding relationships between costs and benefits of FL-reduction interventions

2.1 On the measurement and causes of FL

Despite the growing policy focus, accurate data on FL, especially in LMICs, is missing (Catteneo et al., 2021; Delgado et al., 2021), hampering effective intervention strategies. Studies estimating FLW mainly show figures based on national food balance sheets - which capture food production, import, export, and utilisation at the country level. These are not always exact and reliable, and do not provide insight into where loss occurs along the supply chain. Other estimates are often based on micro-level studies using sample survey data regarding specific supply chain actors but these are costly and time-consuming and it is difficult to get a large enough proportion of responses to represent an entire supply chain or region.

Various definitions
There exists no unambiguous definition and classification of FL in the literature. For instance, some consider loss of agricultural products only originally intended for human consumption, whereas others include inedible (parts of) products as well. Definitions differ in a focus on quantitative (mass or volume) or qualitative (e.g. calories) loss, and in a focus on which actors in the chain attribute loss or waste to.[3] Terms such as 'postharvest loss', 'food loss', 'food waste' and 'food loss and waste' are often used interchangeably. Consequently, estimates of loss – either expressed in quantity, quality, economic or environmental costs – show great variation and are incomparable, even highly inconsistent. As a result the precise causes of food loss equally remain undetected.[4]

The most common definition of food loss and waste is the one applied by FAO (2019):

> *'the decrease in the quantity and quality of food resulting from the decisions and actions of food suppliers along the food supply chain, excluding retail, food services and consumers. Food loss therefore occur at the production, post-harvest and processing stages along the food chain. Food waste, on the other hand, refers to the decrease in the quantity and quality of food resulting from the decisions and actions of retailers, food service providers and consumers' (FAO, 2019).*

Figure 2.1 illustrates this definition. One critique on this definition is that measuring loss starts from what *has been* produced and harvested, while others (among others Sheahan and Barrett, 2017; Delgado et al., 2021) also point out that *potential* production is lost during the growing season due to e.g. poor quality seeds, drought and incorrect disease control, making a case for on-farm interventions to reduce harvest and post-harvest loss.

[3] See Isthangulyyev et al. (2019), comparing definitions of FAO, HLPE, USDA and Fusions EU.
[4] See Delgado et al. (2021), for a more detailed discussion of measurement methodologies, and new methods that account for loss from pre-harvest to product distribution and include both quantity loss and quality deterioration.

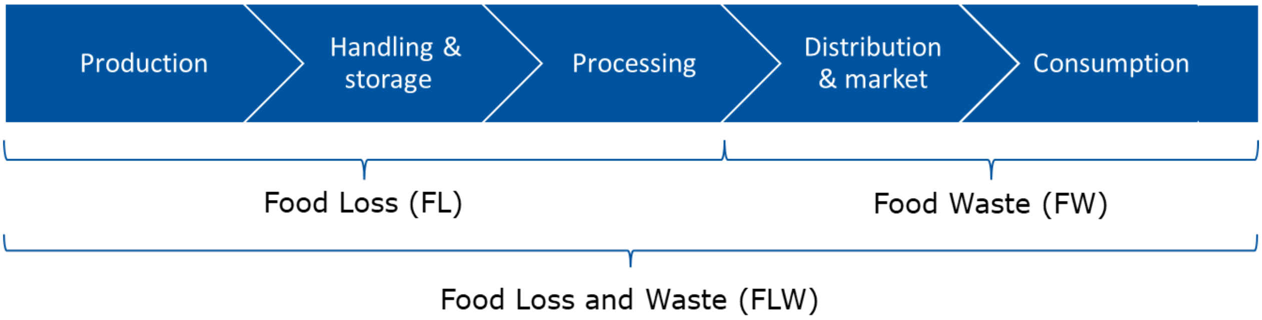

Figure 2.1 *Framework for food loss and waste definitions (Islangulyyev et al., 2019)*

FAO's latest food loss estimates

FAO (2019) presents the first estimates for the Food Loss Index, which indicates that globally – in terms of economic value – around 14% of food produced is lost from post-harvest up to, but not including, the retail level.[5] Estimated loss percentages differ widely between regions, with Central and Southern Asia on the higher end of the spectrum (approximately 20-22% in physical quantity terms) and Australia/New Zealand and Eastern and Southeastern Asia at the lower end (approximately 6-8% food loss) (see FAO, 2019: p. 15 Box 4). Based on a meta-analysis of existing (often country case) studies FAO illustrates how FL varies across stages in the food supply chain, as well as between regions and commodity groups. Generally, levels of loss are higher for fruits and vegetables than for cereals and pulses, but again there is great variation between regions. The meta-analysis also finds a wide range of values for percentage loss at each stage in the food supply chain. This highlights the need to measure FL carefully for specific supply chains to identify where significant losses occur, so as to better understand where to intervene (FAO, 2019: 21-45).

FL causes

FL occurs in all phases of the supply chain, with causes varying in each phase (see Table 2.1, top part, for a comprehensive yet not exhaustive list of causes of FL). Causes of loss in two segments of the supply chain can also be related: for example, primary production of low-quality products can lead to (additional) loss in the processing phase. When addressing the causes of FL, such interconnectedness must be taken into account. Various solutions are discussed in the literature, such as investments in infrastructure, transport facilities and harvesting and/or processing technologies ('hardware'), in addition to investments such as in extension, training, improving knowledge and ability of farmers, workers and inspection services ('software') (see Table 2.1, bottom part). Some of these interventions mainly affect the situation in a certain chain segment (e.g. farmers, primary production), others will have consequences for the magnitude of product loss across several chain segments (such as infrastructure).

[5] 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.

Table 2.1 *Causes of and possible strategies to prevent food loss per stage of the food supply chain*

Production	**Handling and storage**	**Processing and packaging**
Causes		
• Infrastructural limitation • Overproduction/unharvested produce • Harvesting timing • Harvesting method (mechanical versus manual) • Pesticides and fertilisers • Economic problems (e.g. low prices) • Quality standards • Choice of variety	• Degradation and spillage according to product characteristics • Transportation from farm to distribution • Storage infrastructure	• Unavoidable loss • Technical inefficiencies and malfunctions • Methods and changes in processing lines • Contamination in processing lines • Legislation restrictions • Packaging system • Overproduction of refrigerated foods with short shelf live
Possible strategies to prevent food loss		
• Government investments in infrastructure • Improve harvesting techniques • Improve market access • Organise extension services and educate farmers • Increase tax incentives for donating unsellable edible foods	• Improve transportation facilities • Provide access to cheap handling and storage technologies • Invest in storage facilities (warehouses, cold storage, etc.) • Improve the ability and knowledge of workers to employ safe food handling practice • Use of appropriate and clean containers for the products	• Improve capacity of process line • Improve packaging to keep food fresher for longer • Standardise date labels to prevent consumer confusion • Establish other ways to use peels and trimmings • Improve the knowledge and ability of workers • Facilitate sanitary and cleaning inspections

Source: Isthangulyyev et al. (2019).

The list of FL causes and suggested solutions (Table 2.1) displays a somewhat technical bias towards practical solutions to a (FL-related) problem in the supply chain. Flanagan et al. (2019) point to several 'underlying factors' that lead to direct causes. These can be technological, managerial, behavioural or structural in nature. The root causes of FLW are closely intertwined, while a case of FL (or waste) often has more than one cause, with some dominant in certain regions and for individual products. Overall, the authors claim that 15 underlying drivers must be addressed simultaneously to reduce FLW, suggesting that a single measure applied in a single stage of the supply chain may not be very effective, but that a more integrated approach with interventions in different (e.g. technical and institutional) areas is needed to address at least the causes of food loss identified as the most important (Figure 2.2).

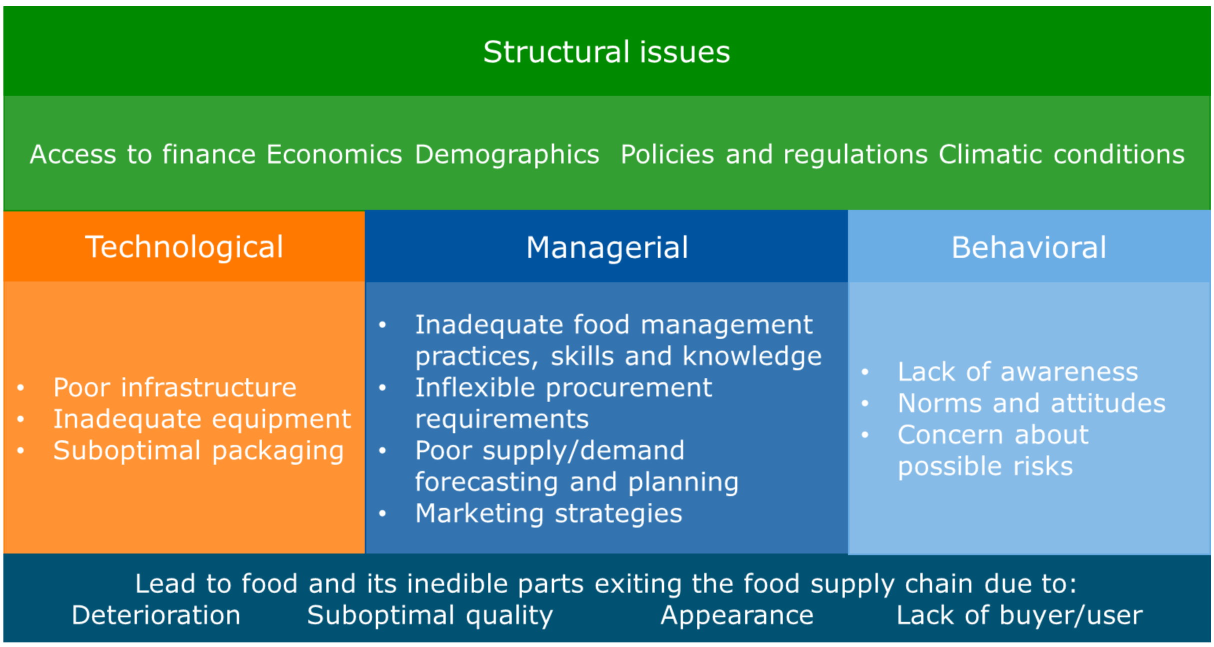

Figure 2.2 *Food lost or wasted is due to multiple underlying drivers*
Source: Flanagan et al. (2019).

2.2 How costs and benefits of measures to reduce FL compare

With many options to limit postharvest loss, the question arises which solution(s) is (are) the most effective, preferably at the lowest possible cost. Analyses of costs and benefits of FL-reducing measures require accurate data and a good understanding of how changes in prices and quantities due to an intervention transmit along the food supply chain.

Using a simple supply and demand diagram based on Rutten (2013) it can be shown graphically how FL interventions may impact producers and consumers (Figure 2.3). The illustration starts by depicting a market for a food commodity with a standard upward sloping supply curve and a standard downward sloping demand curve. The price mechanism ensures that supply equals demand, with an equilibrium price and quantity - P0 and Q0 in Figure 2.3. Tackling FL implies that compared to the situation in which FL remains, more could be produced at the original equilibrium price, or the original quantity produced can be offered at a lower cost if loss were to be absent; in Figure 2.3, the supply curve shifts to the right (from Supply 0 to Supply 1), leading to a lower equilibrium price (P1) and a greater level of consumption (due to averted loss) (Q1). It will also lead to welfare gains),[6] but how the wealth gain will be distributed between producers and consumers depends on the slope of the supply and demand curves, reflecting the responsiveness (or elasticities) (see Box 2.1) of producers and consumers to changes in prices and quantities. Generally, overall welfare and the welfare of consumers generally increases, whereas that of producers could go down in the short run (when the supply is inelastic). The latter occurs when the increase in sales from selling previously lost produce insufficiently compensates for the price decrease on existing sales. Gains in terms of increased revenues, if any, will occur later when demand increases due to lower prices (showing the importance of inter-temporal effects). From Figure 2.3, it can also be seen that the size of the impacts will depend, amongst others, on how big the loss is relative to the size of the market, which varies by type of food and country or region. Whatever the extent of the loss, in terms of quantity, the size of the impact – Q1-Q0 – however, is (much) smaller than the original size of the problem – Q2-Q0 – which is due to the change in the price.

Rutten (2013) also highlights the need to account for broader economic linkages that affect the impacts of a FL-reducing intervention, pointing at trade-offs that occur on the demand side where a reallocation of spending away from previously lost foods towards other products (and perhaps food) causes some producers to be worse off and some to be better off. Moreover, if loss reductions involve costs, then welfare impacts will be lower: FL-reducing investment costs have a price increase effect (the supply curve shifts to the left). Rutten observes a paucity of studies on the costs of reducing food loss, which leads to incomplete and unfounded statements on impacts.

[6] To simplify the explanation changes in welfare gains will not be illustrated graphically.

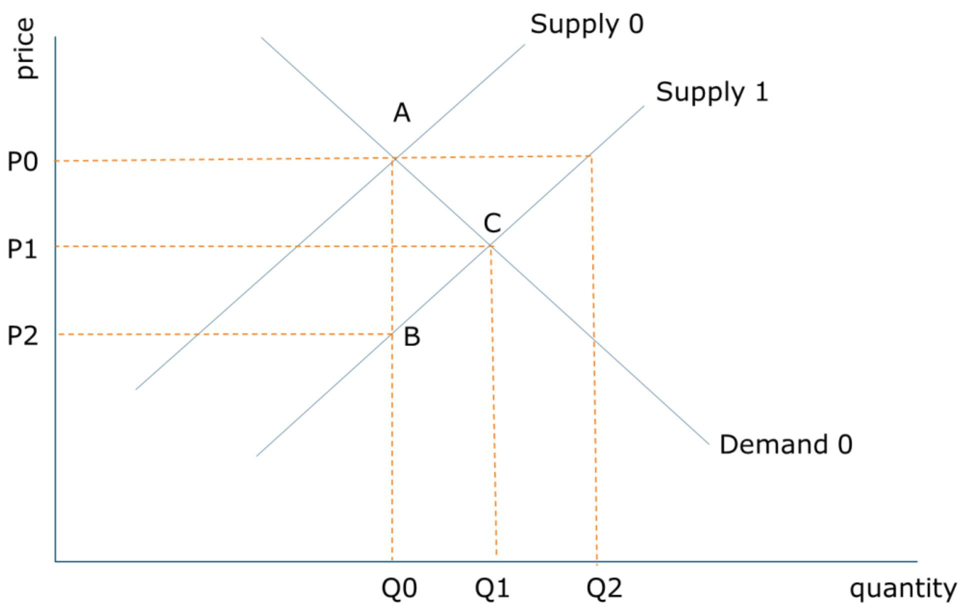

Figure 2.3 *Impacts of reducing food loss in supply*
Source: Rutten (2013).

Box 2.1 Consumer and producer price elasticities

The responsiveness by which consumers and producers adjust levels of consumption and production, respectively, to market prices are determined by the (own-price) demand and supply elasticity. In turn, these elasticities determine the degree by which a FL intervention, and its effect on prices, has an impact on food security or environmental outcomes. Elasticities differ across commodities, countries and income classes (e.g. Bond, 1983; Schiff and Montenegro, 1997; Green, Cornelsen et al., 2013).

First, considering consumer responses, a unit increase in prices effectively implies a reduction in disposable income (income effect), reducing the quantity consumers can purchase as well as a shift to alternative produce (a substitution effect). Food price elasticities are generally inelastic (see table below) implying that the contraction in consumption is less than proportional to an increase in price. Insights from developing countries show that both income and substitution effects of food consumption are considerable, implying price elasticities are higher than in high-income countries (Green, Cornelsen et al., 2013). In the aggregate, food price elasticities in low-income countries are -0.74% compared to -0.56% in high-income countries, implying a 1% increase in prices leads to a reduction of 0.74% or 0.56% in food consumption respectively. Conversely, a decrease in prices leads to consumption increases of similar magnitudes. Furthermore, elasticities differ across food items as shown in the table below. In general, price elasticities are lower for staples, and higher for luxurious, but often nutrient-dense food items, such as meat, fruits or vegetables.

	Fruit and Vegetables	**Meat**	**Fish**	**Dairy**	**Eggs**	**Cereals**	**Fat and Oils**
Low income	-0.72	-0.78	-0.80	-0.78	-0.54	-0.61	-0.60
Middle income	-0.65	-0.72	-0.73	-0.72	-0.48	-0.55	-0.54
High income	-0.53	-0.60	-0.61	-0.60	-0.36	-0.43	-0.42

Source: Green, Cornelsen et al. (2013).

Second, considering the responses of producers to a change in prices it is important to consider differences between the long and the short run. Producer supply responses in the short run are typically less elastic due to fixed and sunken investments and/or agronomic practicalities that inhibit a swift change in production (e.g. Binswanger, 1989). Examples of the latter include scaling up of tree plantation crops (coffee or cocoa), some livestock sectors or irrigated vegetable production. Conversely, supply responses of annual crops are more elastic in the short run. That being said, estimates of supply elasticities for different crops, across different income groups are partial and ambiguous (Kuyvenhoven, Moll et al., 2000). A study by Bond (1983) estimates aggregate short-term food supply response in Africa at 0.18 and long-term elasticity at 0.21, meaning a 1% increase in price leads to a 0.18% or 0.21% increase in supply respectively. Binswanger (1989), citing data from India, suggests supply elasticities of 0.33 for wheat, 0.77 for sorghum and 0.46 for chickpeas. Studies document modest and inelastic supply responses in Africa, attributable to an overall unfavourable investment environment (e.g. Thorbecke, 2000).

FAO (2019) produces a conceptual framework in which such costs of interventions and interactions within the food supply chain and the broader economy are taken into account. A main message is that the effectiveness of reducing FL in generating desirable food security and environmental outcomes depends on how it affects prices across commodities and locations and along supply chains. This analytical framework is briefly presented in Figure 2.4 and explained below.

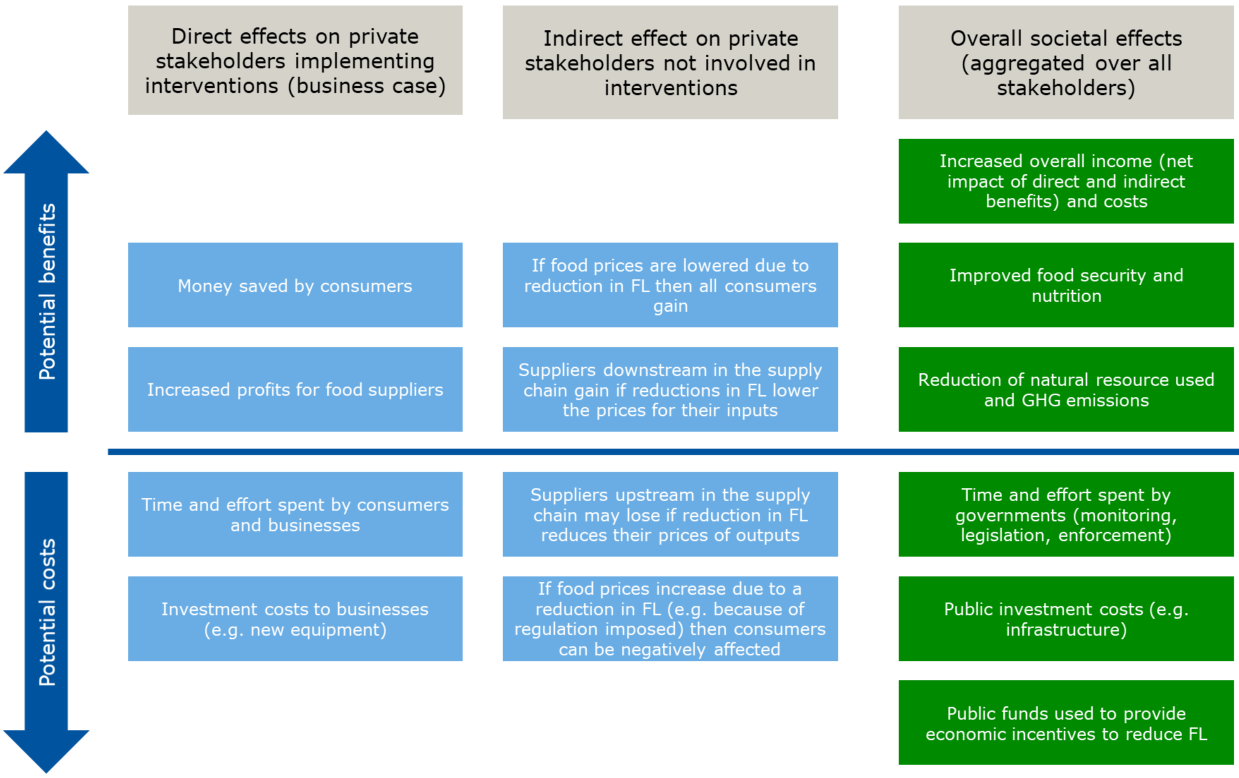

Figure 2.4 *Potential private and broader societal benefits and costs of FL loss reduction*
Source: adapted from FAO (2019), Figure 10, p. 49[7]*.*

Figure 4 lays out that by avoiding food loss and hence using production means more efficiently private actors (farmers, traders, processors) can increase profits and consumers can save money. However, there are costs associated with the intervention, affecting the net benefits of the intervention. Next, for those private stakeholders who are affected indirectly through changes in prices associated with reductions in food loss, the indirect effects depend on where interventions are occurring, and whether stakeholders are upstream or downstream in the supply chain relative to where the price change occurs. Actors operating upstream 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 instance, if processors reduce their loss, farmers may see a decrease in demand that negatively affects their returns but at the same time the reduction in processing loss may make food cheaper for retail and consumers which increases their well-being.

To examine whether society-wide gains (that is, effects aggregated over all stakeholders) exceed the costs of efforts of a loss reduction, the net benefits for private stakeholders – both direct and indirect – are to be aggregated and then impacts on the environment and on food and nutrition security need to be factored in 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 FL. 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 4).

[7] The modification of the original figure only concerns the removal of the reference to food waste. Although the emphasis in this study is on FL-reducing interventions in the supply chain up to retail, the consequences for consumers are also included in this figure. Consumers experience the (positive and/or negative) consequences of market effects of interventions that reduce loss in the chain.

Based on the principle that reducing food loss is not a goal in itself but a means to improving food system outcomes, intervention choices should be linked to desirable outcomes. FAO (2019) provides some guiding principles in relation to objectives pursued with food loss interventions in relation to their entry points in the supply chain:

- For environmental outcomes, interventions may reflect the specific objective that is targeted. For example, if the main objective 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 preserve land or water quantity and quality, interventions closer to the primary production stage may prove most effective, as subsequent stages will add little to the environmental damage. Moreover, 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;
- For health and nutrition outcomes, the gains from cutting loss are at the farm level, by improving resource use efficiency that affect farmers income positively and where fewer loss mean increased food availability that is assumed to improve access to and affordability of food for those suffering from food insecurity;
- For farmers' livelihood outcomes, FL-reduction initiatives should focus on the quantity and quality of production and price levels at points of sale, because these factors bear most directly on farmers' income. Cooling and road infrastructure and other post-harvest facilities are key to success at the market, particularly for perishables.

The next chapter examines to what extent the current literature on the effects of FL interventions has applied the insights discussed in this chapter about market effects and consequences for food security and environmental objectives.

3 Strategies and impacts of FL interventions

3.1 Introduction

FL has many possible causes, occurs at different stages throughout the supply chain, and guidelines are required to set priorities among all options to reduce or prevent food loss in the different places in supply chain. In the US, the EPA (Environmental Protection Agency) has adopted a food recovery hierarchy summarising conventional and alternative methods for managing FLW. In this hierarchy of methods, prevention is equivalent to 'source reduction' (see Figure 3.1); recovery is equivalent to 'feed hungry people'; and recycling is equivalent to 'feed animals,' 'industrial uses,' and 'composting' (Muth et al., 2019). Reclaiming excess edible food for human consumption is the most preferable option and incineration or landfill is the least preferred one, given the high amount of virtual resources lost when food is lost or wasted (Muth et al., 2019). Costs of interventions, laws and rules that may act as barriers or opportunities to invest in prevention, recovery or recycling, and attitudes/behaviour (cultural, social, economic, spatial, natural resource and political factors) determine the opportunities of interventions to prevent or reduce food loss.

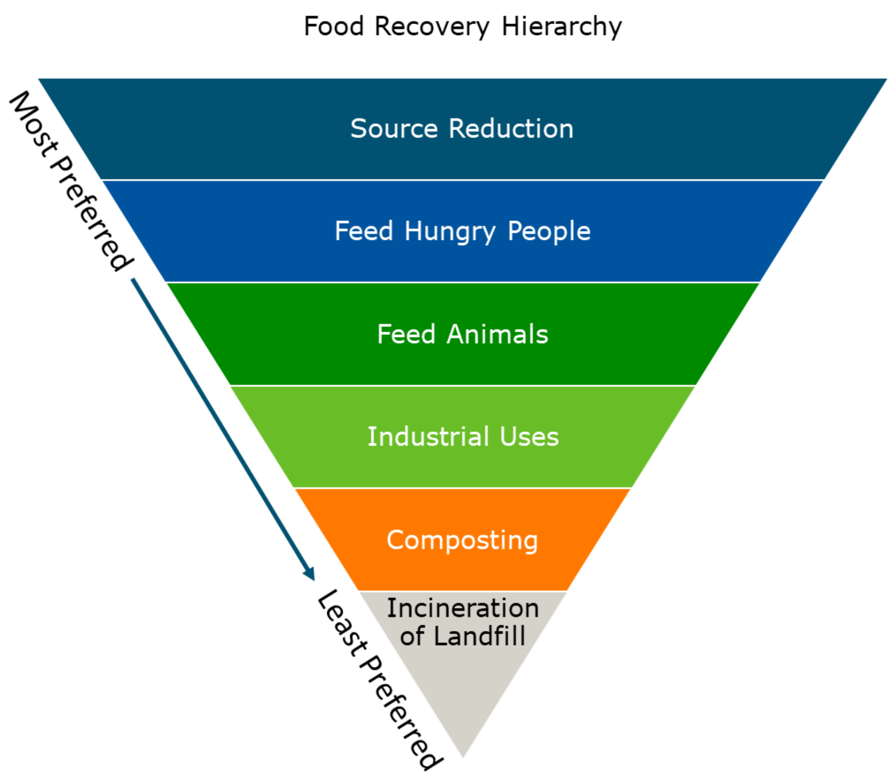

Figure 3.1 *Food Recovery Hierarchy*
Source: Muth et al. (2019).

In the sub-sections below we discuss what the scientific literature tells us about the effects of innovations that are aimed at limiting loss in the food chain (from farmer to processor). In Figure 3.1, this corresponds to source reduction, or using available production resources more efficiently so that more is produced with less inputs. In addition, Section 3.5 will discuss evaluations of choices made with regard to residual flows – that is, situations in which loss has already occurred and for which applications other than human food are sought, for example as animal feed or as an energy source. Also in the valorisation of residual flows, the question is always what the assessment framework is, and which trade-offs or synergies can arise between economic, social and environmental objectives.

3.2 Main adopted innovations to reduce food loss and their impacts

Much scientific research on reducing FL is technical-economic in nature, as Stathers et al. (2020) show in their literature review of 334 studies investigating the impacts of crop post-harvest loss (PHL) reduction interventions in Sub-Saharan Africa and South Asia. Most of the studies focus on building storage facilities for small-scale farmers, while studies of loss-reduction options amongst traders, transporters or other food-system actors were limited. Most of the interventions studied were tangible technologies for reducing loss during storage, while a few studies focused on changes in handling practices or training, and only about 13% of the studies mentioned economic, social or environmental outcomes of the interventions, either separately or combined. Just five of the articles studied the factors affecting the adoption of PHL reduction interventions, with many of the other studies making suggestions regarding barriers and facilitators of the adoption of PHL reduction interventions without supporting data. According to the authors, drawing robust conclusions on the technical efficacy of many of the interventions is difficult because there are relatively few studies of each intervention for each crop, and they vary in scale, duration, type of loss data collected, location and context. Many studies reviewed were conducted only under controlled settings (in a laboratory or on test fields at experimental stations) and did not replicate the interventions outside of it. Most of the included studies involved only researchers without any participation from farmers or other community members, leaving the effectiveness of the intervention in real life and the possible adoption rate by farmers an open question.

Adoption rates of loss reduction interventions are greatly determined by delivering a positive business case in which the required investments balance the economic benefits of the interventions (also in the longer term, considering costs of maintenance of storage facilities, or when costs of initially subsidised inputs increase, see Soethoudt et al., 2021). Over the last twenty years several experiments have been conducted that introduce hermetic bags to store grains for a longer period, reducing PHL and allowing farmers to benefit from seasonal price fluctuations. Reporting on a project providing farming households in two districts in Tanzania with hermetic storage bags, Brander (2021) shows that the intervention reduced the proportion of severely food insecure households by 38% on average in the lean season, and by 20% in the full seasonal cycle. These findings – which are based on farmers' self-assessment of post-harvest loss and food security impacts – demonstrate, according to the author, that a simple and inexpensive technology could contribute strongly to reducing seasonal food insecurity and improving smallholder farmers' year-round access to food. The Purdue Improved Crop Storage bags (PICS) rolled out a storage improvement programme across multiple countries in Sub-Saharan Africa, with quite some success: the adoption of hermetic storage bags (not only PICS bags) is now very common in various areas, such as e.g. up to 91% of farmers in zones in Eastern Kenya. Returns on investment range from 13% to 80%, foremost by allowing farmers to store grains and profit from price fluctuations throughout the season (see Box 3.1 more background information).

Box 3.1 The adoption of improved crop storage bags in Sub-Saharan Africa

The past two decades have seen considerable advance in the promotion and adoption of improved crop storage bags across SSA. One of the most prominent examples of this technology is the Purdue Improved Crop Storage bag (PICS). These bags are made of three layers of plastic, and were initially designed in the early 2000s by a team of researchers of Purdue University together with farmers in northern Cameroon (see PICS website: https://www.purdue.edu/postharvest/). The aim was to design a low-cost improved storage method for cowpea farmers using locally available and accepted materials. Grains should be well dried before storage after which the bags allow for long-term storage of grains, either for human consumption, or saving seeds for next years' crop. The bags allow for storage of cowpeas in quantities of 50kg or 100kg, larger than locally used alternatives, in near oxygen-free conditions (e.g., Baributsa, Lowenberg-DeBoer et al., 2010; Murdock, Margam et al., 2012). In principle, this fully eliminates the need to treat harvested produce with insecticides. In practice, however, many farmers still report to applying insecticides as an additional insurance against post-harvest loss (Moussa, Lowenberg-DeBoer et al., 2011).

Such bags as well airtight containers – another now commonly used storage method – have drastically reduced post-harvest loss of cowpea. Estimates from the 1990s suggest that postharvest loss of cowpea in West Africa, using traditional storage methods, may fall in the range of 25% to 52% (Moussa, Lowenberg-DeBoer et al., 2011) but that improved storage methods reduced loss to less than 1% (same ref). By consequence, and due to the affordability of the bags (€2-€3 per bag), adoption has jumped across countries. A study from 2011 (Moussa, Lowenberg-DeBoer et al., 2011) suggest that already 30% of harvested cowpea across West Africa was then stored using improved storage methods. The use of improved storage bags has been successfully trialled in many other grains (among others maize, rice, wheat) and legumes (groundnut, mung bean) (a full overview on the PICS website) with funding from key donors, notably the Bill and Melinda Gates Foundation. Recent studies now establish equally high rates of adoption in other regions, including eastern Kenya where 91.2% of farmers now use improved storage bags for storing maize and pigeon pea (Baributsa and Njoroge, 2020).

The use of improved storage methods may now be ubiquitous in many parts of SSA for many of the major grains and legumes also witnessed by the fact that many commercial companies now market these improved storage bags (Baributsa and Njoroge, 2020). Many studies display healthy financial returns of investing in these bags (Moussa, Lowenberg-DeBoer et al., 2011; Baributsa and Njoroge, 2020), even though temporary public subsidies may be beneficial for stimulating initial uptake (Omotilewa, Ricker-Gilbert et al., 2019) and document considerable reductions in food insecurity (Brander, Bernauer et al., 2021). Moreover, the prospect of reduced post-harvest loss crowds in farmer investment pre-harvest, for instance in hybrid maize varieties (Omotilewa, Ricker-Gilbert et al., 2018).

Yet caveats remain. One of the initial motivations for developing the improved bags was to offer an alternative to farmers for distress sales immediately after the harvest period (Baributsa, Lowenberg-DeBoer et al., 2010). The reasoning was that the bags allowed farmers to avoid selling at low prices directly after harvest, and profit from higher prices later in the season. Studies, however, reveal that distress sales still occur even when improved storage methods are available. Such sales are thus a signal of acute liquidity constraints and not typically of a lack of storage methods (Kadjo, Ricker-Gilbert et al., 2018).

And despite the availability of studies documenting the success of these methods for specific crops, in specific countries, studies on the breadth and depth of adoption, as well as aggregate effects on prices, food security or environmental effects (i.e. the overall reductions in pesticide use or increased disposal of plastic bags in the environment) are lacking. Additional studies should further establish which types of farmers primarily use these bags, for which products and how this leads to changes in income and food security, as compared with farmers not using such bags and for what reasons.

In line with this topic, Dijkink et al. (2019) provide further interesting insights into both the economic and environmental effects of using hermetic (PICS) bags to limit crop loss in five Sub-Saharan Africa countries. Dijkink et al. (2019) show that by using hermetic bags loss is kept to minimum, while significant loss occurs with standard (woven polypropylene) storage bags after hundred days or more. Consequently, the intervention leads to reduced GHG emissions. However, from an economic point of view, interventions' effectiveness depends mainly on the seasonal price fluctuation of the commodity. The study shows that storage would be profitable for farmers in Uganda in which prices fluctuate significantly over the year, whereas in Zambia, a country with a low seasonal price gap, the investment cannot be earned back (note: a PICS bag of 90kg is about 7-8 times more costly than a standard 90kg PP bag).

An example of how a joint approach to reduce loss does not necessarily provide benefits to all participating parties in the chain can be found in Plaisier et al. (2019), describing pilot projects to reduce loss in the tomato value chain in Nigeria. The authors used a participatory approach (Living Lab workshops) for identifying major causes of loss in tomato production and trade. With local stakeholders the most promising intervention was implemented, replacing raffia baskets with plastic crates during tomato transport. Crates were found to outperform baskets. Weight loss was between 5 and 12% lower with crates than with baskets. Similarly the loss in best-quality A-grade tomatoes was between 16 and 20% lower with crates than with baskets. All participants mentioned benefits of crate use and the majority of participants bought the crates after the project finished, giving a high adoption rate of the implemented intervention. However, several challenges remain. For instance, while retailers and traders had financial gains, most farmers did not benefit from the increased value of tomatoes transported in crates as the pricing of the transaction between the farmer and trader was set at the farm, before transportation, in the majority of cases. Transporters could even have lower income because they were paid per item and the transporters carried fewer items when transporting the larger crates compared to the smaller baskets. This shows that benefits of interventions are not automatically equally distributed among parties in the chain, but that market power, market information and transparency in price agreements also play a role.

As illustrated by the above examples, current literature on FL-reduction interventions is mainly focused on investments in storage facilities and handling practices during transport from the field to the market. Although multiple causes of loss exist (see Table 2.1 in Section 2), interventions for FL reduction in the non-storage stage are little researched, which leads Stathers et al. (2020) to conclude that

'Future research and investments should also cover combinations of training, finance, infrastructure, policy and market interventions that go beyond tangible technologies and handling practice changes'.

Such combinations of investments are potentially delivering broad-based benefits. For instance, Sheahan and Barrett (2017) refer to a study by Minten et al. (2014) on a rapid rise in the number and capacity of cold storage facilities in a potato-producing region in India. It illustrates that the private sector was willing to make major investments following policy changes and investments made by the government, including widespread infrastructure improvements. Another example of a FL-reduction intervention 'beyond storage building' is Soethoudt and Castelein (2020), showing how – under certain assumptions – investments in modern inputs can provide both economic benefits to farmers and reduce GHG emissions (see Box 3.2).

Box 3.2 Food loss reduction strategies for potato-growers in Kenya

In a study on the possibilities of reducing food loss amongst smallholders producing potatoes in Kenya, Soethoudt and Castelein (2020) calculate four scenarios in which the effects of the use of certified seed, fertiliser, pesticides and mechanisation on yields, crop loss and GHG emissions are determined. These are compared with a default situation in which farmers do not, or minimally use these inputs. Farmer yields are substantially higher in the scenario where most external inputs are used. That means significantly less GHG emissions per hectare and per unit of product (including GHG emissions embodied in external inputs and transport). The calculation assumes a given sales volume (of 1,000 kg) at a fixed price – that is, the price does not change as a result of the investment in the inputs. Although the use of mechanisation and external input use requires some investment, profits per ton increase due to higher yields and less loss. The study assumes that the farmer's profit is not skimmed off by parties further down the chain. Also, the study does not discuss the dynamic situation that arises when farmers expand their production, bringing more potatoes to the market with the potential effect of lowering prices and profit margins for the farmer, hence leaving the consequences of scaling-up the intervention an open question.

3.3 Strategies reducing food loss: key messages from studies illustrating trade-offs between food security and environmental objectives

3.3.1 Model simulations addressing the link between food loss reduction and food system outcomes

A number of studies simulate the effects of measures aimed at reducing food loss using what is called an integrated model (Kuiper and Cui, 2021; Van Vuuren et al., 2019; Springmann et al., 2018; Willett et al., 2019). Such models can be used to assess the joint changes in economic, biophysical and environmental indicators as a result of FL-reduction interventions. In doing so they provide insights into the trade-offs between different goals, because they can estimate the effects of an intervention simultaneously for the socio-economic, biophysical and environmental domains.

Kuiper and Cui (2021) combine FAO's 2019 food loss estimates for primary production and processing stages with an economy-wide global simulation model (MAGNET) to simultaneously determine the impact of a costless uniform 25% FL reduction on food security (availability, accessibility and utilisation) and environmental indicators (agricultural land use, GHG emissions).[8] A detailed decomposition is made of changes in both food security and environmental indicators with respect to food loss reductions by region, supply chain stage and sector – an important difference with the other references mentioned in the previous paragraph, which only present global results for the whole agricultural sector. The comparative static analysis shows that food security and environmental impacts are most significant and positive in low-income regions. Next, in low-income regions such as Sub-Saharan Africa the reduction of FL in the primary production stage of fruit and vegetables has the most significant and positive effects on food security indicators whereas loss reductions in the primary livestock sector (animal products) show greatest impacts in terms of GHG emission reductions in all regions (with respect to the latter Guo et al., 2020 draw the same conclusion). The outcomes lead to three main policy recommendations: (1) focus on primary stage food loss reductions; (2) concentrate on fruit and vegetables, and animal products; and (3) do not lose sight of imports substituting for domestic production. The latter means that food loss interventions elsewhere in the world can affect domestic producers and consumers, via cheaper imports: domestic consumers benefit from this, but farmers do not as they face increased competition from foreign supply.[9] Based on their model results, Kuiper and Cui suggest to further explore reducing loss in primary production of fruit and vegetables at country level if the main goal is to improve food security, but especially to reduce loss in the animal sector if the focus is on limiting environmental damage. The authors recognise the absence of actual interventions and their implementation costs to achieve the simulated FL reductions is a main limitation of the study. Moreover, as the authors stress, FL reduction gains should be weighed not only against the intervention costs, but also against alternative means to reach the food security and environmental objectives (see Section 3.4).

3.3.2 Ambiguous relationship between food loss reduction intervention and environmental outcomes

A key motivation for reducing food loss is that produced, but not consumed, food still leads to greenhouse gas emissions and claims land and water, that can be avoided by limiting these production loss. Following this argument, the scope for reducing the environmental footprint is a common and dominant policy objective associated with interventions to reduce food loss (UN 2016). However, it remains to be seen to what extent an intervention to combat food loss actually removes environmental concerns, as any intervention leads to adjustments in supply and demand, which should be considered in order to estimate what can be saved by not producing food that is currently lost.

---

[8] FL reduction is implemented as an exogenous shift in productivity at primary and processing stages to proxy a wide range of changes contributing to achieve such a reduction but unexplained within the model such as new technologies, policy changes, and increased FL awareness.

[9] See also Rutten et al. (2015), for an illustration of the ripple effects through international trade. This study analyses the 2020 impact of FLW reduction in the European Union on Sub-Saharan Africa, showing producers in the latter region losing due to cheaper imports while consumers in both regions benefit from lower prices.

Three factors may explain why environmental outcomes may not (always) improve due to a food loss reduction. First, the net environmental effects of the proposed technical FL intervention may itself be negative. An example is the case of extending the store life of fresh vegetables through a lower refrigeration temperature. The carbon emissions from increased energy for refrigeration could surpass the amount of carbon embodied in additionally saved produce (Broeze, Guo et al., 2019). To assess the impact of a specific technical intervention (first reason above), tools such as the ACGE (Broeze, 2019) help in calculating the net environmental impact.

Second, reductions in FL will translate into lower prices for consumers. Savings on food purchases may shift consumption to other environmentally damaging goods, with studies (e.g. Kuiper and Cui, 2021) showing that net carbon savings from FL reductions are therefore typically much lower than expected. The implication is that policies that target environmental externalities directly, such as environmental regulation or a carbon tax, could be more cost-effective in reducing environmental footprints than FL (Cattaneo, Federighi et al. 2021).

Third, environmental improvements upstream (at the farm-level) due to reductions in FL could be surpassed by additional environmental pressures due to increased consumption and associated increases in downstream transport, packaging or energy costs (Cattaneo, Federighi et al., 2021). For understanding whether a food loss reduction will also lead to a net environmental improvement, detailed insights into changing market prices, quantities consumed and produced, and the environmental footprint associated with different stages of a particular commodity supply chain are therefore required (see Chapter 5).

3.4 Alternative approaches to food loss reduction interventions to reach the same objectives

The above evaluation of food loss interventions not only show ambiguous impacts but also begs the question whether targeted policies and tools other than food loss reduction interventions would be better suited – i.e. at lower costs, contributing to multiple SDG objectives and for more stakeholders – to tackle food insecurity and unsustainable production. For example, there is broad consensus that food insecurity is primarily caused by poverty, not food loss, while food loss is clearly not a driver of poverty. Since many people in developing countries depend on agriculture for their livelihood, productivity growth in the agricultural sector is an important tool to fight poverty. Sheahan and Barett (2017) emphasise once again that using better seeds, other modern inputs and crop disease prevention are effective to increase labour productivity in agriculture, while such investments potentially reduce pre-harvest loss. Moreover, these authors claim, measures to increase agricultural productivity and more efficient use of resources already on-farm, for instance through extension services, may be more cost-effectively contributing to increasing profits for farmers *and* reducing greenhouse gas emissions at the same time.

In turn, infrastructural limitations (e.g. roads, digital and/or power networks) are often mentioned as an important factor causing food loss (Isthangulyyev et al., 2019). Rosegrant et al. (2015) are among the few that have examined the relationship between PHL and food security on the basis of a global analysis, concluding that there is a strong correlation between a lack of infrastructure and FL. In this study, the hunger-reduction potential of increased investments in post-harvest reduction is estimated assuming a scenario where a 10% reduction in the post-harvest loss is maintained globally by 2030 through increased investments in infrastructure. Obviously there are much cheaper ways of preventing or limiting FL. But what matters is what consequences such an intervention aimed at reducing FL has on food security. Investments in paved road networks, railways and electricity power networks show to be effective measures to reduce food loss. At the same time, there are other advantages to infrastructural improvements than just FL reductions, such as lower transport costs of goods to the market, so that prices of the supply can be sold more competitively. Infrastructural investments may therefore have a greater effect on poverty reduction and food security than investments in better stock facilities only.

Smallholders' adoption rates of post-harvest loss reducing technologies are constrained by limited access to financial markets (Stathers et al, 2020: add other refs). Sheanan and Barrett (2017) recall that

> *'A significant development economics literature details the many ways in which financial market failures manifest in seemingly-inefficient behaviors in commodity markets, technology uptake, etc., but that the best approach to addressing these 'displaced distortions' is commonly to address the root underlying financial market failure rather than to treat the behavior – such as inefficient storage with a high PHL rate – that is merely its symptom'.*

Access to credit can be improved by well-established land ownership titles that can serve as collateral for loans. This and other measures to enhance small-farmers' creditworthiness will offer them the possibility to invest in better stock facilities, but one can also choose to invest in productivity growth. Strengthening the creditworthiness of smallholders can therefore be a highly effective pathway contributing to poverty alleviation and strengthening food security, whereby farm investments can lead to reduced crop loss, even though the main objective is to increase labour productivity and enhance farm profitability.

Chichaibelu et al. (2021) show that PHL reduction interventions have merit in contributing to food security but may not be the most cost-effective. In this study, 22 interventions are assessed for their influence on SDG2 (Zero Hunger) and the least-cost intervention with the highest potential to reduce hunger and malnutrition are identified. Estimates on the effects of FL-reduction measures along the supply chain are based on Rosegrant et al. (2015). The information about the interventions is drawn from best available evidence-based literature, including modelling studies and impact assessments.[10] Most of the investments considered for ending hunger also support the income and productivity targets, hence reducing hunger in sustainable ways. Some of these interventions can be implemented in the short term (such as social protection), others in the longer term (such as agricultural R&D, or soil fertility management).

The results from the analysis indicate that achieving SDG 2 does not have to be prohibitively expensive (an extra USD 11-14bn per annum over the next ten year to lift 500 million people out of hunger and malnutrition),[11] provided that a mix of least-cost measures with large hunger and malnutrition reduction potential are prioritised. The mix of the identified low cost, high-impact interventions include agricultural R&D, agricultural extension services, digital agricultural information systems, small-scale irrigation expansion in Africa, female literacy, and some scaling up of existing social protection programmes (see Figure 3.2).

[10] The study's findings are based on a set of comprehensive and long-term research programmes and partnerships among a large international research community: 1) International Food Policy Research Institute (IFPRI), International Institute for Sustainable Development (IISD), and Cornell University: Ceres2030: Sustainable Solutions to End Hunger; Ending Hunger, Increasing Incomes, and Protecting the Climate: What would it cost? https://ceres2030.org/. 2020; 2) Center for Development Research (ZEF), University of Bonn and United Nations Food and Agriculture Organization (FAO): FAO): Investment Costs and Policy Action Opportunities for Reaching a World without Hunger (SDG 2), Bonn and Rome, Oct 2020; 3) ZEF and Akademiya2063: From Potentials to Reality - Transforming Africa's Food Production, Bonn and Dakar, Oct 2020.

[11] This is roughly equivalent to a doubling of current G7 development assistance for agriculture, food security and rural development. However, to prevent 840-900 million people from hunger – which is the 2020 estimate of hunger projection in 2030 - an additional USD 39-50bn per annum over ten years until 2030 is needed.

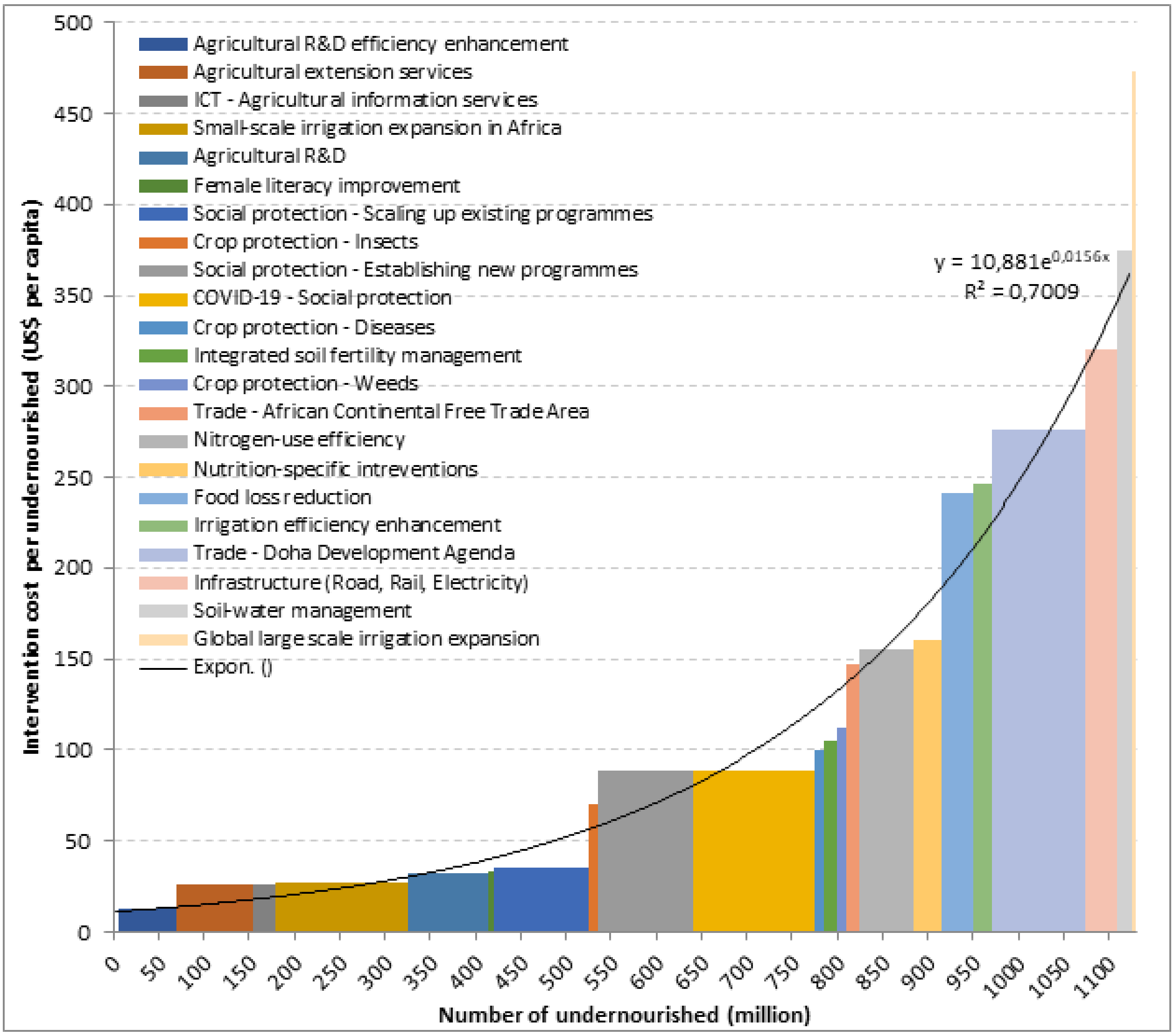

Figure 3.2 *Marginal cost curve of the suggested interventions to eradicate hunger and malnutrition*
Source: Chichaibelu et al. (2021).
Note: This figure shows the cost of each hunger reduction measure such that each bar represents a single intervention where the width shows the number of individuals lifted out of hunger, the height its associated per-capita cost, and the area its associated total cost. The total width of the MACC reflects the total hunger reduction possible from all interventions, while the sum of the areas of all of the bars represents the total cost of reducing hunger (NoU) through the implementation of all interventions considered. The positions of the bars along the MACC reflect the order of each intervention by their cost-effectiveness. When moving along the MACC from left to right, the cost-effectiveness of the interventions declines as each next intervention becomes more expensive than the preceding.

3.5 Valorisation of agri-food residues: food system impacts of recycling and re-using residual biomass [12]

Studies and strategies to reduce FL, as discussed above, largely focus on using inputs more efficiently to prevent food being lost in the supply chain. Yet, food loss does occur, some avoidable, some unavoidable, and loss can be repurposed. This section discusses the opportunities of valorising food or biomass residues and the potential impacts recycling and re-using such residues may have on food system outcomes.

[12] In this literature most authors do not distinguish between food loss and waste, yet use the term food waste in most cases.

FL is associated with economic and environmental costs. After all, part of what is produced by food supply actors (farmer and food processors) is not marketed and will not lead to economic revenues, but will incur production costs. Loss also implies a wastage of natural resources and production-related negative environmental effects. A logical idea is to capture the production that is lost in the food chain and use it as a raw material for, for example, animal feed, packaging or compost, in order to reduce the economic and environmental impact of occurring FL. The literature in which options for valorisation of FL is analysed shows that there are still economically viable applications and that the environmental effects can be positive if processing and repurposing costs relatively little (fossil) energy.

A quick scan of scientific literature on valorisation of agricultural and food residual flows reveals that most studies are of a technical nature (e.g. O'Connor et al., 2021; Teigiserova et al., 2019).[13] Most studies discuss the technical possibilities of converting agri-food residues into a usable product in an experimental laboratory or scenario setting. Examples of key valorisation techniques are fermentation, extraction, drying, hydrolysis, enzymatic treatment/conversion and anaerobic digestion/co-digestion (see for more extensive overviews of valorisation techniques, for instance, Mahari et al., 2022; O'Connor et al., 2021; and, Nayak and Bhushan, 2019). The examples in literature show that applications of processed residual flows are assumed almost infinite, whereby the opportunities for applications of residual flows are often investigated by decomposing the flows into protein, fibre, carbohydrate, minerals and other components of the processed residual biomass.

A much-discussed complication in the processing of residual agri-food flows is that it has many sources (agriculture, industry, restaurants, households) and consists of many different components, including metals and other substances that are potentially toxic to humans or animals, or may contaminate soil or water. Consequently, separation of received residual flows into usable and unusable parts strongly influences the production costs of the recycled product. In addition, countless combinations of residual flows are possible, for example to extract compost or energy, but also the variation in products that can be made from residues is enormous (also from a 'pure' residual flow as for instance Gil and Maupoey, 2018, show in their case on pineapple waste). This makes economic feasibility studies very product and context specific, the latter because availability of local agri-food residues, efficient infrastructure and national/region-specific regulations or government support are among the key factors determining the success of circular business models (Donner et al., 2021). Consequently, economic feasibility assessments of circular pathways are based on rough estimations of costs (including assumptions of scale of operations) and potential returns on such investments under different scenarios of market prices, compared to those for which the renewable product can be a substitute. In their extensive review of literature on options for valorisation of residual flows from the food industry, Caldera et al. (2020) note that relatively few studies analyse the profitability of valorisation techniques thoroughly. The authors conclude that

> *'key aspects for a comprehensive economic assessment such as the availability of a sufficient quantity of the waste stream considered and logistic issues, including the identification of the generation points of such wastes and the location of the biorefinery, have been overlooked in the literature'.*

Most literature on this topic highlights the environmental benefits of valorisation agri-food residues, based mainly on (a variant of) Life-Cycle Assessment (LCA)[14] (e.g. Mayson and Williams, 2021; Mosna et al., 2021; Caldeira et al., 2020; Scherhaufer et al., 2020; Mak et al., 2020; Isoni et al., 2018). Such LCAs make different methodological choices: most LCAs focus on the environmental impact assessment of one valorisation process or on the comparison of alternative technologies to obtain a value-added product from the residual biomass; others evaluate the environmental impact of the product produced from the residue in comparison with a traditionally produced substitute, including a part that is disposed of in landfills or

[13] A literature search in ScienceDirect using keywords 'Food residue valorization', 'Trade-off', 'economic', and 'environment' gives 404 relevant publications (journal/research articles and book chapters), the majority appearing in Renewable and Sustainable Energy Reviews (36), Journal of Cleaner Production (32), Bioresource Technology (20), and Science of The Total Environment (20). Following a scan of abstracts we narrowed the selection to those articles in which economic feasibility and/or environmental impact issues were addressed. This led to a selection of 65 articles that were studied in more detail.

[14] LCA is an international standardised method to evaluate the environmental impacts of a product, process, or activity throughout its life cycle. A variant method is Life Cycle Costing (LCC), which is a cost management approach that concerns the development of a product during its product life cycle, which is from the cradle to grave.

incinerated (see Caldeiro et al., 2020, for a discussion of the LCA methodologies applied in residue valorisation literature). Although studies point to a potential reduction in GHG emissions in the case of recycling food loss, they also point to the often energy-intensive techniques required to separate residual flows into usable (pure) components, and subsequently convert them into a usable product (e.g. O'Connor et al., 2021; Scherhaufer et al., 2020). At the same time, the scale of production, required transport for the delivery of residual flows and the relative market price in relation to the substitute also influence the applied valorisation technique and thus the net environmental effect of an application. In addition to the many variables that need to be considered in the analysis, good reliable data to calculate costs and potential savings or revenues are necessary to determine the environmental and economic effects of valorising residual biomass techniques. For the time being, studies are mainly based on estimates and are scenarios.

In conclusion, research into promising valorisation pathways of residues is mainly technical in nature. Studies show that there are countless conversion and application possibilities, whereby potential environmental benefits appear to be achieved depending on the conversion technique used. Whether an application is economically promising also strongly depends on the product and the local context. However, few studies assess technical options for biomass residue valorisation in specific local contexts. There are even fewer studies into options for valorisation of biomass residues that simultaneously weigh economic, social and environmental impacts. This makes it very difficult to choose a valorisation technique and application from a systems perspective. As a second-best option, valorisation pathways could be chosen that score best on one of the system objectives – for example, increasing income – without the results on other objectives – for instance reducing environmental damage – being negatively impacted.

4 Key messages and guidelines for assessing food loss reduction interventions

This report highlights that policy for effective interventions to prevent or reduce food loss is complicated by the lack of sufficiently detailed and reliable data on where in the supply chain and how much loss occurs, and what is the real underlying cause of FL.

Interventions to reduce loss have consequences for chain actors that the intervention is aimed at (for example farmers) but also elsewhere in the chain, and there are winners and losers – or, advantages and disadvantages – of a measure. In the broader context of achieving the SDGs, reducing FL is not an end in itself but a potential means to contribute to enhancing food and nutrition security and more sustainable food system outcomes.

Key messages of this report are:

1. Impacts of FL-reduction interventions on food system outcomes depend on many factors, such as the kind of product, the (root) cause of FL, the location and the extent of FL, where it occurs across stages in the supply chain, and the costs and benefits of interventions applied to private stakeholders, to government and/or society;
2. FL reduction can be an effective strategy that contributes to better food system outcomes, but not by default: detailed inquiry is needed to determine which tool to use where in the supply chain for the most effective leverage. When applied, there can be winners and losers, that is, actors that benefit from the intervention and those that do not gain. Moreover, there may be important trade-offs of FL interventions between food security and environmentally sustainable production objectives;
3. Other targeted policies and instruments than food loss reduction interventions may be better suited to address food insecurity and unsustainable production;
4. Research into promising valorisation pathways of residues is mainly technical in nature and few studies *simultaneously* weigh economic, social and environmental impacts. This makes it very difficult to choose a valorisation technique and application from a systems perspective.

In the Dutch food security policy – which mainly aims to contribute to SDG 2 – reducing FL is seen as an important instrument for strengthening both food security and ecologically sustainable production systems (see Policy letter on Food Security). FL interventions can have positive effects on both objectives (on either or both at the same time), but not by default and depend strongly on specific contexts. To understand when and where positive outcomes could materialise one has to take into account price transmission effects – interventions affect prices at places in the chain other than where the intervention is carried out – scaling-up effects on market prices when interventions are applied on a larger than an individual scale, and socio-economic and cultural factors that may be obstacles to adopting proposed innovations. The assessment of the potential impact of a proposed FL-reduction strategy or intervention, ex ante, requires assessing the:

- expected effects of an intervention aiming at reducing FL in economic, social and environmental fields;
- alternative interventions (other than FL reduction) that can help achieve policy priority objectives.

In other words, a detailed comparison needs to assess whether food loss positively contributes to some of the broader societal goals (economic, social and environmental) without negatively affecting others. For doing so, some guiding principles can be established. The scheme below summarises the main insights described in studies above including Rutten (2013), Catteneo et al. (2021), taking along insights on GHG emission embodies in production of specific agricultural commodities (Crippa, Solazzo et al., 2021; Xu, Sharma et al., 2021).

The decision-making scheme that should be read in conjunction with Table 4.1 and the further clarifying Table A1 in the Appendix serve two uses. First, it can be a guideline for assessing a specific project proposal to reduce FL. The scheme can be used to provide a quick scan, even with limited information, in order to screen proposals. It may quickly identify interventions that are unlikely to contribute to policy goals, yet for a considerable group of interventions the potential contribution to policy goals may be more ambiguous and requires more in-depth study.

Second, the steps presented in Table 4.1 (on the main supply/demand characteristics of the commodities where a lot of food is lost and ex-ante estimated costs and benefits of the intervention) can be carried out as generic steps at the country level which can serve as a 'national food loss policy plan'. Such a comprehensive policy plan ideally combines insights on both various technical options to reduce FL in commodity chains, as well as ex-ante insights on equilibrium effects on economies and societal indicators. The latter can be based on integrated simulation study or other integrated methods to quantify and compare costs and benefits to societies (LCA, Societal Cost-benefit Analysis). On the basis of such a policy plan, suggestions can be made to local (or regional) authorities and other stakeholders in the relevant supply chains for projects to reduce loss, while also indicating how support from the Dutch private sector and/or knowledge institutions can be obtained. Such a policy plan helps to create local support, and ensures a more strategic and cost-effective use of this instrument in Dutch policies to contribute to global food security policy.

Table 4.1 *Preparatory steps for uncovering whether a food loss (FL) reduction proposition contributes to food security and environmental policy goals cost-effectively*

Step #	Description of step in decision-making scheme
A	Pick a high loss commodity
B	Does the proposed intervention target a stage in the supply chain where food loss is large, or largely shapes loss in subsequent stages? • If yes, the proposed FL intervention could be cost-effective, move to step C. • If not, the advice would be to reconsider the FL intervention for a different supply chain stage
C	Can reasonable estimates on the following key characteristics of market price formation be retrieved, in particular, • Are consumers responsive to price changes (i.e. what is the consumer price elasticity of the targeted commodity)? • Are producers responsive to price changes (i.e. which is the producer price elasticity of the targeted commodity)? • To which degree do changes in prices transmit through the supply chain? • If yes (data available), move to step D1 • If no, move to step D1, but acknowledge much greater uncertainty in establishing potential impact of the proposed intervention
D1	Estimate the costs of the proposed FL intervention per unit of product marketed (of the stage of the supply chain the intervention is in). and identify which actor in the supply chain bears these costs primarily. Can this actor recoup these costs making this a revenue-neutral or positive intervention? • If yes, move to the decision scheme presented in Figure 4.1. The actor is incentivised to implement the FL-reduction intervention, but be aware of possible adverse outcomes to other actors. • If no, the FL-reduction intervention may still yield considerable benefits to other actors, or societal benefits. Move to D2.
D2	Can public support in the short- or long-run, be matched in order to achieve success? • If yes, move to the decision scheme presented in Figure 4.1. • If no, proposed intervention is unlikely to contribute to food security or environmental policy goal cost-effectively.

Crucial in preparing a national plan for food loss reduction is the availability of reliable data. So measuring and monitoring food loss in the different chain segments is a first and essential basic part of a general plan, and without that 'step A' is not really possible. Two additional remarks on data finding are the following.

Step B requires detailed understanding on the supply chain organisation of the commodity and country considered. In particular understanding the magnitude of loss, where do they occur and by what cause. Relevant data could be retrieved from existing international studies and databases (FAO), or (preferably) from country-level assessments. Alternatively, food loss and waste data collection procedures can be used (e.g. Kok et al., 2021).

In addition, Step C is aiming at increasing insights in how interventions affect producers and consumers/users of the commodity and how responses in one segment of the supply chain will impact actors in other supply chain segments. For this we need insights in how price responsive producers and consumers/users are, and price changes transmit through the supply chain. Data to answer these questions can be derived from Box 2.1 (Section 2.2), or country-level studies. In general, consumer price responsiveness is higher for dairy and meat products, as well as fruits and vegetables, and lower for staple crops. However, producer price responsiveness is often largest for annual staple crops. Producers of perennial crops, or commodities where capital investments are high (may apply to dairy and meat products, as well as fruits and vegetables), are less responsive to price changes. The degree of price transmission is highly context specific. In general, it is higher when supply chains are short, transport costs are low, and if there is strong competition (less concentration) between traders and middlemen.

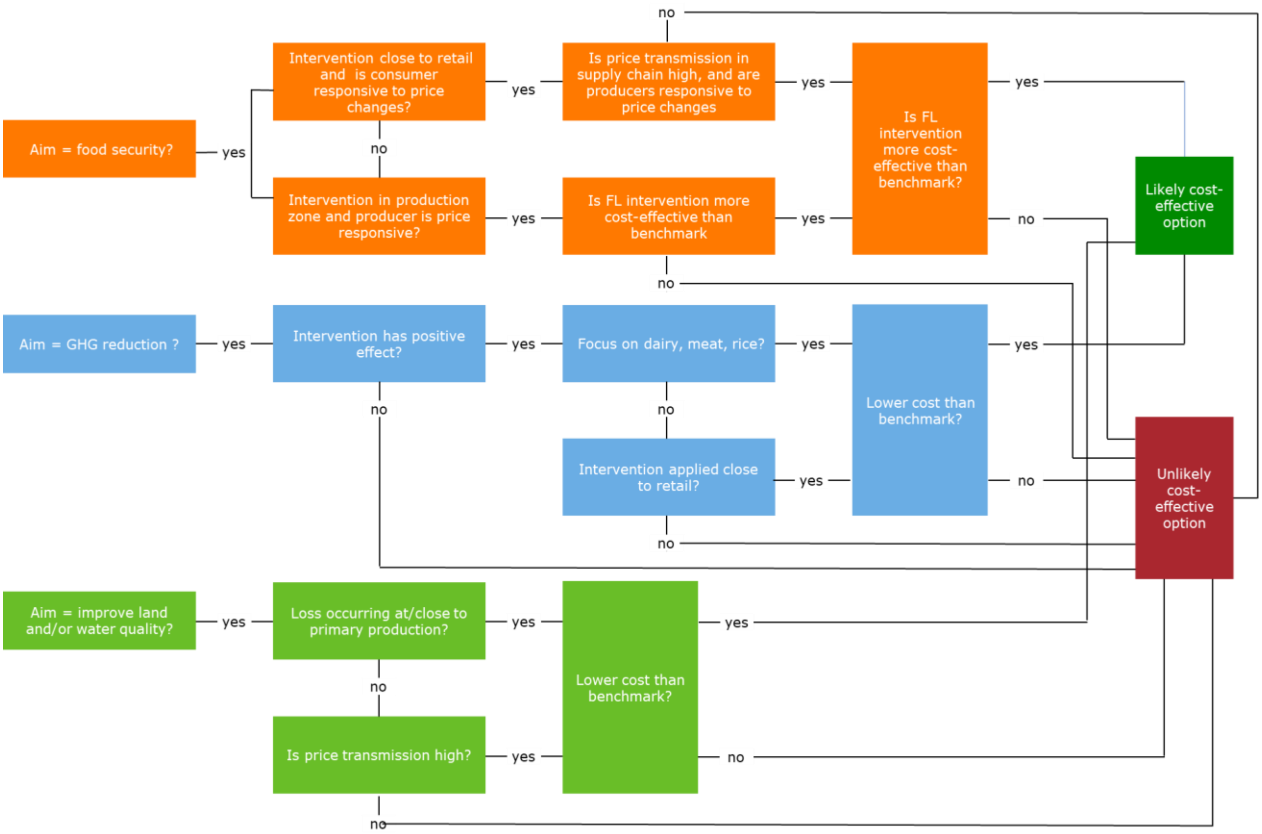

Figure 4.1 *Decision-tree for uncovering whether a food loss (FL) reduction proposition contributes to food security and environmental policy goals cost-effectively (See Appendix Table A1 for further clarification)*

As outlined throughout this report, the scale of FL varies widely across commodities as well as countries with options to reduce FL being manifold. The flow diagram in Figure 4.1 can therefore only provide a very generalised structure, but still highlighting the key questions and types of information required for a proper assessment of the impact of proposed FL-reduction interventions. The step-by-step plan emphasises once again that before proceeding with an intervention, a considerable number of choices must be made to determine whether it will be meaningful and effective.

Sources and literature

Baributsa, D., J. Lowenberg-DeBoer, L. Murdock and B. Moussa (2010). Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges. 10th International Working Conference on Stored Product Protection.

Baributsa, D. and A.W. Njoroge (2020). 'The use and profitability of hermetic technologies for grain storage among smallholder farmers in eastern Kenya.' *Journal of Stored Products Research* 87: 101618.

Brander, M., T. Bernauer and M. Huss (2021). 'Improved on-farm storage reduces seasonal food insecurity of smallholder farmer households – Evidence from a randomized control trial in Tanzania.' *Food Policy* 98: 101891.

Broeze, J., X. Guo and M. Vollebregt. Forthcoming. 'A Systematic Approach for Trade-Off Analysis of Food Loss Reduction and Greenhouse Gas Emissions.' *International Journal of Life Cycle Assessment*.

Caldeira, C., A. Vlysidis, G. Fiore, V. de Laurentiis, G. Vignali and S. Sala (2020). Sustainability of food waste biorefinery: A review on valorisation pathways, techno-economic constraints, and environmental assessment. *Bioresource Technology* 312 (2020) 123575. https://doi.org/10.1016/j.biortech.2020.123575

Cattaneo, A., M.V. Sanchez, M. Torero, and R. Vos (2021). Reducing food loss and waste: Five challenges for policy and research. *Food Policy* 98 (2021) 101974 https://doi.org/10.1016/j.foodpol.2020.101974

Catteneo, A., G. Federighi, and S. Vaz (2021b). The environmental impact of reducing food loss and waste: A critical assessment. *Food Policy* 98 101890. https://doi.org/10.1016/j.foodpol.2020.101890

Chichaibelu, B.B., M. Bekchanov, J. von Braun and M. Torero (2021). The global cost of reaching a world without hunger: Investment costs and policy action opportunities. *Food Policy* 104 (2021) 102151. https://doi.org/10.1016/j.foodpol.2021.102151

Delgado, L., M. Schuster and M. Torero (2021). Quantity and quality food losses across the value Chain: A Comparative analysis. *Food Policy* 98 (2021) 101958. https://doi.org/10.1016/j.foodpol.2020.101958

Donner, M., A. Verniquet, J. Broeze, K. Kayser and H. de Vries (2021). Critical success and risk factors for circular business models valorising agricultural waste and by-products. Resources, *Conservation & Recycling* 165. https://doi.org/10.1016/j.resconrec.2020.105236

Dijkink, B., J. Broeze, H. Axman and M. Vollebregt (2019). Economic perspective in different Sub-Saharan African countries, food security and greenhouse gas emissions. Working paper no. 291 CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

EAT-Lancet Commission (2019). Food in The Anthropocene: the EAT-Lancet Commission on Healthy Diets From Sustainable Food Systems. *Lancet* 2019; 393: 447–92

FAO (2019) State of Food and Agriculture. FAO Rome

Flanagan, K., K. Robertson and C. Hanson. 2019. Reducing Food Loss and Waste: Setting a Global Action Agenda. Washington, DC: World Resources Institute.

Fusions, 2016. Estimates of European food waste levels. Stockholm. https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf.

Gil, L.S. and P.F. Maupoey (2018). An integrated approach for pineapple waste valorisation. Bioethanol production and bromelain extraction from pineapple residues. *Journal of Cleaner Production* 172 (2018) 1224e1231. https://doi.org/10.1016/j.jclepro.2017.10.284

GLOPAN (Global Panel on Agriculture and Food Systems for Nutrition) (2016). Food systems and diets: Facing the challenges of the 21st century. London, UK.

HLPE, Food Losses and Waste in the Context of Sustainable Food Systems; High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security: Rome, Italy, 2014

Ishangulyyev, R., S. Kim and S. Hyeon Lee (2019). Understanding Food Loss and Waste—Why Are We Losing and Wasting Food? *Foods* 2019, 8, 297; doi:10.3390/foods8080297

Isoni, V., D. Kumbang, P.N. Sharratt and H.H. Khoo (2018). Biomass to levulinic acid: A techno-economic analysis and sustainability of biorefinery processes in Southeast Asia. *Journal of Environmental Management* 214 (2018) 267e275. https://doi.org/10.1016/j.jenvman.2018.03.012.

Kadjo, D., J. Ricker-Gilbert, T. Abdoulaye, G. Shively and M. N. Baco (2018). 'Storage losses, liquidity constraints, and maize storage decisions in Benin.' *Agricultural Economics* 49(4): 435-454.

Kok, M.G., R.B. Castelein, J. Broeze and J.C.M.A. Snels (2021). The EFFICIENT protocol. A pragmatic and integrated methodology for food loss and waste quantification, analysis of causes and intervention design. Wageningen University and Research.

Kuiper, M. and H.D. Cui (2021). Using food loss reduction to reach food security and environmental objectives – A search for promising leverage points. *Food Policy* 98 (2021) 101915. https://doi.org/10.1016/j.foodpol.2020.101915

Lipinski, B., C. Hanson, J. Lomax, L. Kitinonja., R. Waite and T. Searchinger (2013). Reducing Food Loss and Waste. Creating a Sustainable Future Working Paper Series No. 2. World Resources Institute, Washington, DC.

Mahari, W.A.W., K. Waiho, H. Fazhan, M.C. Necibi, J. Hafsa, R.B. Mrid, S. Fal, H. El Arroussi, W. Peng, M. Tabatabaei, M. Aghbashlo, F. Almomani, S.S. Lam, and M. Sillanpää (2022). Progress in valorisation of agriculture, aquaculture and shellfish biomass into biochemicals and biomaterials towards sustainable bioeconomy. *Chemosphere*, Vol. 291, Part 2,2022, https://doi.org/10.1016/j.chemosphere.2021.133036.

Mak, T.M.W., X. Xiong, D.C.W. Tsanga, I.K.M. Yua and C.S. Poon (2020). Sustainable food waste management towards circular bioeconomy: Policy review, limitations and opportunities. *Bioresource Technology* 297, 122497. https://doi.org/10.1016/j.biortech.2019.122497

Mayson, S. and I.D. Williams (2021). Applying a circular economy approach to valorize spent coffee grounds. *Resources, Conservation & Recycling* 172 (2021) 105659. https://doi.org/10.1016/j.resconrec.2021.105659

Mosna, D., E. Bottani, G. Vignali and R. Montanari (2021). Environmental benefits of pet food obtained as a result of the valorisation of meat fraction derived from packaged food waste. *Waste Management* 125 (2021) 132–144. https://doi.org/10.1016/j.wasman.2021.02.035

Moussa, B., J. Lowenberg-De Boer, J. Fulton and K. Boys (2011). 'The economic impact of cowpea research in West and Central Africa: A regional impact assessment of improved cowpea storage technologies.' *Journal of Stored Products Research* 47(3): 147-156.

Murdock, L. L., V. Margam, I. Baoua, S. Balfe and R. E. Shade (2012). 'Death by desiccation: Effects of hermetic storage on cowpea bruchids.' *Journal of Stored Products Research* 49: 166-170.

Nayak, A. and B. Bhushan (2019). An overview of the recent trends on the waste valorization techniques for food wastes. J*ournal of Environmental Management* 233, 352–370. https://doi.org/10.1016/j.jenvman.2018.12.041.

O'Connor, J., S.A. Hoang, L. Bradney, S. Dutta, X. Xiong, D.C.W. Tsang, K. Ramadass, A. Vinu, M.B. Kirkham and N.S. Bolan (2021). A review on the valorisation of food waste as a nutrient source and soil amendment. *Environmental Pollution* 272. https://doi.org/10.1016/j.envpol.2020.115985

Omotilewa, O. J., J. Ricker-Gilbert and J. H. Ainembabazi (2019). 'Subsidies for Agricultural Technology Adoption: Evidence from a Randomized Experiment with Improved Grain Storage Bags in Uganda.' *American Journal of Agricultural Economics* 101(3): 753-772.

Omotilewa, O. J., J. Ricker-Gilbert, J. H. Ainembabazi and G. E. Shively (2018). 'Does improved storage technology promote modern input use and food security? Evidence from a randomized trial in Uganda.' *Journal of Development Economics* 135: 176-198.

Plaisier, C., M. Sibomana, J. Van der Waal, L. Clercx, C.P.A. Van Wagenberg and Y. Dijkxhoorn (2019). Approach for Designing Context-Specific, Locally Owned Interventions to Reduce Postharvest Losses: Case Study on Tomato Value Chains in Nigeria. *Sustainability* 2019, 11, 247; doi:10.3390/su11010247

Rosegrant, M.W., E. Magalhaes, R. Valmonte-Santos and D. Mason-D'Croz, (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. http://www.copenhagenconsensus.com/sites /default/files/food_security_nutrition_assessment_-_rosegrant_0.pdf.

Rutten, M.M. What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agric & Food Secu***r 2,** 13 (2013). https://doi.org/10.1186/2048-7010-2-13

Sheahan, M. and C.B. Barrett (2017), Review: Food loss and waste in Sub-Saharan Africa. Food Policy vol. 70, p. 1-12. http://dx.doi.org/10.1016/j.foodpol.2017.03.012.

Scherhaufer, S., J. Davis, P. Metcalfe, S. Gollnow, F. Colin, F. De Menna, M. Vittuar and K. Östergren (2020). Environmental assessment of the valorisation and recycling of selected food production side flows. *Resources, Conservation & Recycling* 161 (2020) 104921. https://doi.org/10.1016/j.resconrec.2020.104921

Stathers, T., D. Holcroft, L. Kitinoja, B.M. Mvumi, A. English, O. Omotilewa, M. Kocher, J. Ault and M. Torero (2020). 'A Scoping Review of Interventions for Crop Postharvest Loss Reduction in Sub-Saharan Africa and South Asia'. *Nature Sustainability* 3 (10): 821–35. https://doi.org/10.1038/s41893-020-00622-1.

Soethoudt, H. and B. Castelein (2020). Food Loss-Reducing Intervention Strategies for Potato Smallholders in Kenya—A Positive Business Case with Reduced Greenhouse Gas Emissions. *Agronomy* 2021, 11, 1857. https://doi.org/10.3390/ agronomy11091857.

Springmann, M., M. Clark, D. Mason-D'Croz, K. Wiebe, B. L. Bodirsky, L. Lassaletta, W. de Vries, et al., 2018. Options for Keeping the Food System within Environmental Limits. *Nature* 562 (7728), 519. https://doi.org/ 10.1038/s41586-018-0594-0.

Teigiserova, D.A., L. Hamelin and M. Thomsen (2019). Review of high-value food waste and food residues biorefineries with focus on unavoidable wastes from processing. *Resources, Conservation & Recycling* 149 (2019) 413–426. https://doi.org/10.1016/j.resconrec.2019.05.003.

UN, 2019, SDG12.3. https://sdgs.un.org/goals/goal12

Van Vuuren, D.P., D.L. Bijl, P. Bogaart, E. Stehfest, H. Biemans, S.C. Dekker, J.C. Doelman, D.E.H.J. Gernaat and M. Harmsen (2019). Integrated scenarios to support analysis of the food–energy–water nexus. *Nature Sustainability*, Vol 2, 1132, pp. 1132–1141, www.nature.com/natsustain.

Willett, W., J. Rockstrom, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, Tara, et al. (2019). Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems. *The Lancet* 393 (10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

WRI (World Resource Institute) (2018). Creating a sustainable food future. A menu of solutions to feed nearly 10 billion people by 2050. Synthesis report. https://www.wri.org/our-work/project/world-resources-report/publications

Appendix 1

Table A.1 *Steps for uncovering whether a food loss (FL) reduction proposition contributes to food security and environmental policy goals cost-effectively*

Which are the pre-established policy ambition or goals to which this intervention intends to contribute? **Does the intervention aim to increase food security by increasing supply (food availability) and/or at lower prices? If yes, move to 1a.** **Does the intervention aim to contribute to achieving environmental objectives like reductions in GHG emissions or improving land and water security? If yes, move to 1b.**			
1a	**Considering food security objectives** Does the FL intervention take place in the supply chain close to the retail level? Are consumers responsive to price changes (holds more so for dairy, meat products, fruits and vegetables)? • If yes to both, the proposed FL reduction is most likely to be an effective option to increase food security in the short-run through an increased supply (food availability) at lower prices (food affordability). Move to step 6a • If yes to the FL intervention takes place close to retail: lower prices may not increase consumption. But lower prices do imply consumers may expand consumption of other goods, indirectly increasing food security. Move to step 2a • Else, move to step 3a	1b	**Considering environmental objectives.** Specifically, does the intervention aims to contribute to: • GHG reductions (Move to step 2b) • Improvement in land and water security? (Move to step 6b)
2a	Is price transmission in the supply chain high, i.e. will consumer price changes quickly result in producer price changes? And are producers responsive to price changes (holds more so for staple crops)? • If yes to both, producers will quickly face a lower farmgate price and reduce production which counteract the initial effect of loss reduction (i.e. more food available) on food security will be small. This FL intervention may still stimulate more efficient use of land and water resources (with positive environmental effects). Move to 6a. • If no to either, producers will adjust production only in the long-run, if at all, and greater supply at lower prices may persist in the long-run. Move to 5a.	2b	Will the proposed intervention (for instance, additional packaging versus produce saved) has net positive benefits on GHG emissions, for instance, by using tools such as ACGE (Broeze 2019)? • If yes, move to step 3b • If no, move to 9
3a	The FL-reduction intervention does take place close to the zone of production. Are producers responsive to price changes (holds more so for staple crops)? • If yes, producers will quickly face a lower farmgate price and reduce production. The effect on food security will be small. This FL intervention may still stimulate more efficient use of land and water resources (consider 7b). Move to 6a. • If no, move to 4a	3b	Does the FL-reduction intervention consider an intervention in dairy, livestock or rice production? • If yes, GHG emissions associated with primary production are large relative to emissions embodied in processing, transport and sales. The FL intervention is most likely to display net positive changes. A positive outcome is most likely when producers quickly respond to lower prices (holds more so for rice, but less so for livestock and dairy), and consumers are less responsive to price changes (holds more so for rice than livestock and dairy). Move to step 5b. • If no, move to 4b.

4a	Is price transmission in the supply chain high, i.e. will producer price changes quickly result in consumer price changes? • If yes, improvements in food security can be expected with a greater supply at the market due to inelastic producer responses (increase in food availability) at lower prices (increase in food affordability), at least in the short run. Benefits with respect to land and water use efficiency will be smaller. Move to 5a • If no, inelastic producer responses will imply a greater supply of produce in the market (increase in food availability), but smaller levels of price transmission do not readily translate into lower prices for consumers. Due to great uncertainty on food security impacts we recommend to look for alternative intervention option(s). Move to 9.	4b	Does the FL intervention take place in the supply chain close to the retail level? • If yes, proposed FL intervention may present a cost-effective option to reduce GHG emissions. Move to 5b. • If no, GHG emissions embodied in primary production, relative to processing and transport, are small and a FL-reduction intervention is much less likely to yield a net reduction in GHG emissions, or may even lead to increased GHG emissions. Move to 9.
5a	Are the required public costs, and the overall cost-effectiveness (i.e. euros per unit increase in food security) comparable, or more favourable, than existing alternatives to increase food security in Figure 6)? • If yes, the proposed FL intervention is expected to cost-effectively enhance food security through greater market supply at lower prices, primarily benefiting consumers. Be aware that groups of producers may lose out when lower prices are insufficiently offset by additional revenue from previously lost food. • If no, move to step 9	5b	How large are these costs in terms of euros spent per ton of GHG emissions prevented and are these costs lower than benchmark traded prices of emission rights in carbon markets (ETS) and/or lower than the social cost of carbon? • If yes, the proposed FL intervention likely presents a cost-effective option to reduce GHG emissions. • If no, move to 9.
6a	The proposed FL intervention may only have a small impact on food security. Are the required public costs, and the overall cost-effectiveness (i.e. euros per unit increase in food security) comparable, or more favourable, than existing alternative to increase food security in Figure 6)? • If yes, despite the small expected impact, the proposed FL intervention is expected to cost-effectively enhance food security. • If no, move to 9	6b	Is loss occurring at or close to the stage of primary production, where pressure on land and water resources are also greatest? • If yes, producers will quickly face a lower farmgate price and reduce production. Move to 8b. • If no, move to 7b.
		7b	Is price transmission in the supply chain high, i.e. will producer price changes quickly result in consumer price changes? • If yes, producers will quickly face a lower farmgate price and reduce production, Move to step 8b. • If no, move to step 9.
		8b	The proposed FL-reduction intervention may provide a useful option to reduce pressure on land and water resources. Are the required public costs, and the overall cost-effectiveness (i.e. euros per unit increase in land and water use efficiency) comparable, or more favourable, than existing alternatives? • If yes, the proposed FL intervention is expected to cost-effectively enhance land and water use efficiency. • If no, move to 9
9	The proposed intervention is unlikely to contribute to the set policy goal cost-effectively.		

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
wur.eu/economic-research

REPORT 2022-039

To explore the potential of nature to improve the quality of life

Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
The Netherlands
T +31 (0) 70 335 83 30
E communications.ssg@wur.nl
wur.eu/economic-research

Report 2022-039
ISBN 978-94-6447-159-5

The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,800 employees (6,000 fte) and 12,900 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.