A journey into the world's food systems in search of losses, waste and ways to solve them

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Preface

By Louise O. Fresco

President of the Executive Board of Wageningen University
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June 2022

Momentum for food loss and waste prevention

Cutting food loss and waste is one of the more effective ways to benefit food security, the economy, and the environment. It contributes significantly to the mitigation of climate change and biodiversity loss, two of the most urgent challenges of our times. I have been advocating action to reduce food loss and waste globally for years. Since 2016 as an active member of the global coalition of leaders called Champions 12.3, but also throughout my international career and within the WUR community.

For me, food loss and waste is an exemplary topic for the larger transitions we must manage in our food systems. On the one hand, it is tangible and understandable for everyone in their respective households. It provides us with daily opportunities to make impactful sustainable choices when we buy, cook, and store our food without wasting it. On the other hand, food loss and waste is symptomatic of how our highly complex food systems are full of lock ins, trade-offs, and often lack incentives for transformation.

The role of science in this domain

I have seen the momentum for action on this issue grow and flourish over the years, but large-scale action and impact are still lagging. Science has a role to play here. WUR has been at the forefront of the food loss and waste agenda in the Netherlands, in Europe, and in the world. Private companies have a role to play as well and are needed to scale up and accelerate action. Science can help to formulate, validate and substantiate innovative waste-free products, services, supply chains, and policies. Especially for Low- and Middle-Income countries where losses are often high and food security is at risk, there is a world to gain.

Stepping up the game

In order to deliver on SDG (Sustainable Development Goals) Target 12.3, there is an urgent need to step up our game. ‘Loss- and waste-free’ has the potential to become the new social norm, both for consumers as well as for companies, with their license to operate at stake. I encourage readers to take this call to action to heart and ensure all food systems actors are involved, so the transition can not only accelerate, but also become more inclusive, equal, and just. I hope you will enjoy reading this publication and feel encouraged to seek collaboration with my colleagues at WUR on pursuing future pathways toward impact.

Chapter 01.

Introduction

Reducing food loss and waste (FLW) is not an end in itself but a means to an end.

Interventions aiming at reducing FLW should contribute to enhancing food and nutrition security and more sustainable food system outcomes.

Siemen van Berkum
Sanne Stroosnijder
Vera Vernooij
Bob Castelein

Tackling food loss and waste – From the 'what' to the 'how'

An estimated one-third of all food produced for human consumption is lost or wasted and goes uneaten each year, accounting for about 8% of global greenhouse gas emissions and an estimated loss of 1 trillion US dollars a year (FAO, 2019; IPCC, 2019; UNEP, 2021). Although precise data remains scarce, these losses and waste have a profound impact: although the global food system produces sufficient food to feed 10 million people, according to a FAO study, to date 690 million people (8.9%) are hungry, nearly 2 billion (25%) experience moderate or severe food insecurity, 144 million children (21%) are stunted and 47 million children (7%) are wasted as a result of deficiencies in their diet and their families' diets (FAO et al., 2020). Nearly one in three people in the world (2.37 billion) did not have access to healthy diets in 2020 – that is an increase of almost 320 million people when compared to the year before (United Nations, 2021). These figures have most likely even increased in the last years during the COVID-19 pandemic, amid impacts of climate change and global political and civil unrest (for example the current war in Ukraine).

Based on these premises, the reduction of FLW has gained widespread momentum in policy circles during the past decade as a particular means to enhance food availability for the poor and vulnerable, as well as to mitigate the environmental footprint of the agricultural sector. This focus on FLW has further culminated in the inclusion of FLW in the Sustainable Development Goals (SDGs) in 2015, making reduction a global concern, with the target (SDG 12.3) to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses by 2030.

Within the SDGs, FLW reduction serves a larger goal of ensuring responsible consumption and production (SDG 12), and contributes towards other SDGs related to food security, equitable economic development, and environmental responsibility. Accordingly, interventions aimed at reducing food losses should therefore be assessed on their contribution to food and nutrition security, efficiency, inclusiveness (distribution effects) and reducing environmental pressure. Wageningen University & Research has been at the forefront of the Dutch, European and international food loss and waste reduction movement, developing technical as well as organizational solutions to address the issue of FLW, and advocating for a systemic perspective on FLW and its implications across food system outcomes. Reducing FLW should not be viewed as a goal or end in itself, but rather as a means to achieve multiple goals related to sustainable development. In turn this begs the question as to whether (policy) interventions implemented to reduce FLW serve to achieve these goals simultaneously, always and everywhere, or whether trade-offs between these goals may arise in some instances.

A deep dive into FLW reduction recommendations

There is no shortage of general ideas on what strategies may work to mitigate FLW. In the last decade, dozens of high-level reports have been issued by international organisations (e.g. EU, FAO, IPCC, UNEP, World Bank) and private sector organisations, both nonprofit and corporates (e.g. McKinsey, NRDC, WRI, WWF). Due to the food system dynamics described above, however, there is a mismatch between the plethora of high-level recommendations made for an international policy audience, and the practical implementation of FLW-reducing strategies in the actual food systems, where the desired impact on a range of outcomes is anything but guaranteed.
Through this publication - upon our own initiative and supported by the WUR knowledge base programme on food and water security - we strive to bridge this gap by letting researchers with extensive experience in the implementation and evaluation of FLW reduction strategies reflect on selected high-level recommendations and provide inspiration as to how we can better connect theory (***what*** should happen?) to practice (***how*** is this best realised?) for sustainable impact.

An example of distributional effects of an intervention among system actors

In low-income countries, reducing on-farm losses may have strong, positive food security effects for some farmers – but not for all – and for consumers. The loss reduction may especially benefit smallholder subsistence farmers by increasing the availability of food to them. But farmers who market part of their output may see drops in demand and price, with negative implications for their incomes and thus for their food security, as larger volumes may cause prices to drop at later points in the supply chain. Such price drops benefit consumers. Reducing food waste by consumers will likely improve food availability and access for the same consumers – yet the resulting reduction in consumer demand may leave farmers and other supply chain actors worse off.

To get a grasp on the strategies and interventions that are already part of the discourse, we have collected all recommendations for FLW reduction strategies from 31 authoritative, high-level reports from the past 10 years, augmented with recommendations discussed in 34 academic review studies focusing on FLW reduction. In total, we listed over 800 recommendations that we then grouped in 66 distinct themes, subsuming similar recommendations from different sources. Although of course this specific way of clustering (being more an art than a science) can be discussed, unmistakably across the food supply chain and all domains of the food system there are plenty of recommendations available covering what may help to mitigate FLW.
From this, we ask ourselves the following question: What happens when one starts to implement these strategies in practice, and how does one contend with complex contexts, constraints, stakeholders, and other dynamics of the food system when doing so – i.e. how do we move from the ***what*** to the ***how***?

A food system approach to include trade-offs between policy goals

To answer this question, a food system approach is a helpful tool to investigate in greater detail how FLW interventions lead to impact. A systems approach is particularly suitable for revealing 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 losses and consumer food waste is an important strategy for improved resource efficiency, enhanced food and nutrition security and reduced environmental impacts (e.g. HLPE, 2014; WRI, 2018). However, the impacts of FLW reduction on food security or the environment remain ambiguous and highly conditional on stakeholder relationships and the local context (see Sheahan and Barrett, 2017; FAO, 2019). Moreover, FLW-reducing interventions may have a negative environmental impact when the resources required for FLW reduction are disproportionate, or when the savings from reduced FLW lead to increased consumption of other goods.
Equally important to consider is the potentially different impact on diverse groups of stakeholders of interventions to reduce FLW. A global perspective on FLW reduction suggests that it leads to improvements in both food and nutrition security and the environment – if less food is lost, less needs to be produced to improve global food and nutrition security, thereby also reducing the environmental impact. However, the existence of current levels of FLW could also be interpreted as an economically efficient outcome across diverse actors in the current system. Interventions to reduce FLW may tilt the balance, creating winners and losers throughout the food system (see the text box below for an illustration). When the potential losers are not compensated, they have no incentive to prevent or reduce FLW.

Contribution of food systems research

Together, these observations illustrate that interventions aimed at reducing FLW do not automatically lead to the achievement of intended environmental or social policy objectives. Applied research in this area therefore contributes to policy interventions in three ways (see also Catteneo et al., 2021).

- • The first is to understand the causes and identify why food loss and waste occur, where in the food supply chain and how much (in quantity and/or quality terms). This is to provide insight into the core and size of the problem.
- • The second, to suggest the most effective and efficient pathways to reach desired goals, showing the costs and benefits to stakeholders involved. These are to be linked to the cause, the location and the extent of FLW and the stage where they occur along the food supply chain.
- • The third, to analyse the relationships between actors in the food system in order to fully understand their interactions and behaviour when an intervention aiming at reducing FLW is introduced and implemented. Having insights into food system actors' relationships, research helps to show the potential trade-offs and regional/local diversity in potential effects of the interventions aimed at reducing food loss and waste.

The above points also mean that targeted policies and tools other than FLW-reduction interventions may be better suited - i.e. at lower costs, benefitting multiple SDG objectives and for more stakeholders - to tackle food insecurity and unsustainable production (see the text box below for an example). This can be accomplished while still (indirectly) reducing food loss or waste.

To date, much FLW research is technical-economic in nature and takes place in a controlled ('laboratory') situation, leaving the effectiveness of the intervention in real life and the possible adoption rate by food system actors an open question (Stathers et al., 2020). The challenge of FLW research is to deliver more empirical evidence on how exactly FLW investments can positively contribute to food systems. The results of such analyses should also be weighed up as much as possible against alternative instruments to a food system that delivers safe and healthy food and is inclusive, sustainable and efficient.

FLW-mitigation in relation to other food system outcomes – An example

There is broad consensus that food insecurity is primarily caused by poverty, not FLW, and no one is arguing that FLW is 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 in many of these countries. Using better seeds, other modern inputs and crop disease prevention are ways to help achieve productivity gains and improve farmer livelihoods, while such investments also help reduce pre-harvest losses. Moreover, measures to increase agricultural productivity and to use existing inputs more efficiently also contribute to the reduction of greenhouse gas emissions and loss of resources (Sheahan and Barrett, 2017).

In this volume

The chapters in this volume explain how high-level FLW recommendations can be translated into concrete actions, solutions and pathways. The authors highlight (new) insights from scientific and/or practice-oriented research that contribute to finding solutions to aid the transition towards sustainable food systems. From the broad selection of recommendations we collected, the contributing researchers had the freedom to elaborate on those recommendations that fit their experience and expertise. Some aspects or strategies are therefore undoubtedly not being discussed at the depth they deserve. As such, this volume is not intended to reflect the full spectrum of recommendations made to mitigate FLW, but rather to illustrate how insights from scientific and applied research can be brought to bear to bridge the gap between high-level recommendations and impactful implementation. To support this narrative throughout the volume, the different contributions have been grouped under three overarching themes, each moving closer from the conceptual systems-level thinking to the implementation context 'on the ground'.

Part A.

A systems perspective on Food Losses & Waste

In this section, the authors address the issue of FLW from a systems perspective, setting the scene of this volume by illustrating how different ways of conceptualizing FLW within the food system context informs insights and more deliberate decision-making on intervention strategies. First, in Chapter 2, Siemen van Berkum and Ruerd Ruben outline the elements of circular food systems, with reduced losses and waste and efficient use of material flows, and the principles by which these can be created from our current, predominantly linear, food system. Subsequently in Chapter 3, Bertram de Rooij, Arjen Koomen, and Xuezhen Guo explore the relationship between FLW and the environment, and what an understanding of this relationship can deliver in terms of opportunities for valuable new insights and better tailored and targeted interventions, as well as more effective outreach to stakeholders and society. Last, in Chapter 4, Michele Pedrotti and Daniele Fattibene provide a perspective on food waste in urban food systems, as with growing cities being important players in the current food system, tackling the complex issue of urban food waste is essential to facilitating the transition towards more sustainable and circular food systems.

Part B.

Intervention strategies

In this section, the authors discuss how general recommendations for FLW-reducing interventions relate to the food system contexts in which they are to be implemented. This starts with the question of selecting the right intervention pathways and entry points for implementation in the food system, as Herman Brouwer and Helena Posthumus illustrate in Chapter 5. For this, they present The Food System Decision Support Toolbox, which offers guidance for conducting a food system analysis with the participation of a diversity of chain actors, leading to actionable recommendations. As Michele Pedrotti and Jan Verschoor emphasise in Chapter 6, food loss is a global problem, but needs local solutions. Therefore, they discuss how to adapt interventions and technologies to the specific local implementation context, the food value chain, and the food product, in order to develop effective interventions to reduce postharvest losses. In Chapter 7, Jan Broeze and Wolter Elbersen dive into the circular valorisation of agri-food residues and waste. Decision-making in this domain can be paralysed by the tension between waste hierarchies that propose fixed priorities (e.g. ‘extraction of food components is more circular than applying it as animal feed’) and constraints imposed by different contexts, materials and applications. To bridge the gap between high-level guidelines and practical valorisation strategies, they propose a more flexible framework that prioritises potential applications based on estimates of yield efficiency and functionality per component in an application. In Chapter 8, Ine van der Fels-Klerx addresses the issue of food safety control as a key contributor to reducing FLW. In LMICs, prevention and control of food safety risks related to fungal infection and mycotoxin contamination can contribute to food safety and food security, but food safety management practices are not yet common among the midstream operators in the food value chain in LMICs. This chapter offers several pathways to make the right food safety knowledge, technology, and practices accessible to farmers and small business operators in LMIC. In Chapter 9, Bob Castelein explores the recommendation for ‘short food supply chains’ in a food system context, including the questions regarding what it actually means to ‘shorten’ food supply chains, how this may reduce FLW, what this practically looks like in different food system contexts, and – most importantly – when and whether this makes sense as a strategy to reduce FLW. Lastly, in Chapter 10, Katrine Soma introduces the potential of insects (in particular the black soldier fly larvae) as a novel protein source for food and feed, and explores how insect-based aquaculture feed can be a profitable opportunity for fish farmers in LMICs.

Part C.

A systems perspective on interventions

While the previous part dealt with selecting and implementing the right intervention for the specific food system context, Part C broadens the scope again by considering the systemic implications of FLW reducing interventions. In Chapter 11, Herman Snel discusses the partnerships and incentives that are needed to scale FLW mitigation strategies. He observes that the technology to prevent and reduce losses is there, but application and adoption is lacking due to deficient collaboration and incentives. Combinations of interventions and targeted policy action should be combined to create the necessary incentives for true impact. Finally, in Chapter 12, Bart de Steenhuijsen Piters focuses on the role of informal midstream value chain operators in reducing FLW. Informality greatly challenges the adoption of FLW-reducing practices and technologies in LMIC food systems, especially when driven by policy makers and investors who are used to dealing with formal operators. This chapter invites these and other stakeholders to think more 'out of the box', to reach out and leverage the potential of informal operators to mitigate FLW throughout the food chain.

This volume concludes with a discussion of the lessons learned across these chapters, highlighting both complementarities and points of tension between different approaches and priorities. Most importantly, the volume also closes with a call to action – to get inspired, to take an active interest in our food system, and to think about ways we can all contribute to making our food system more sustainable and equitable.

Suggested reading

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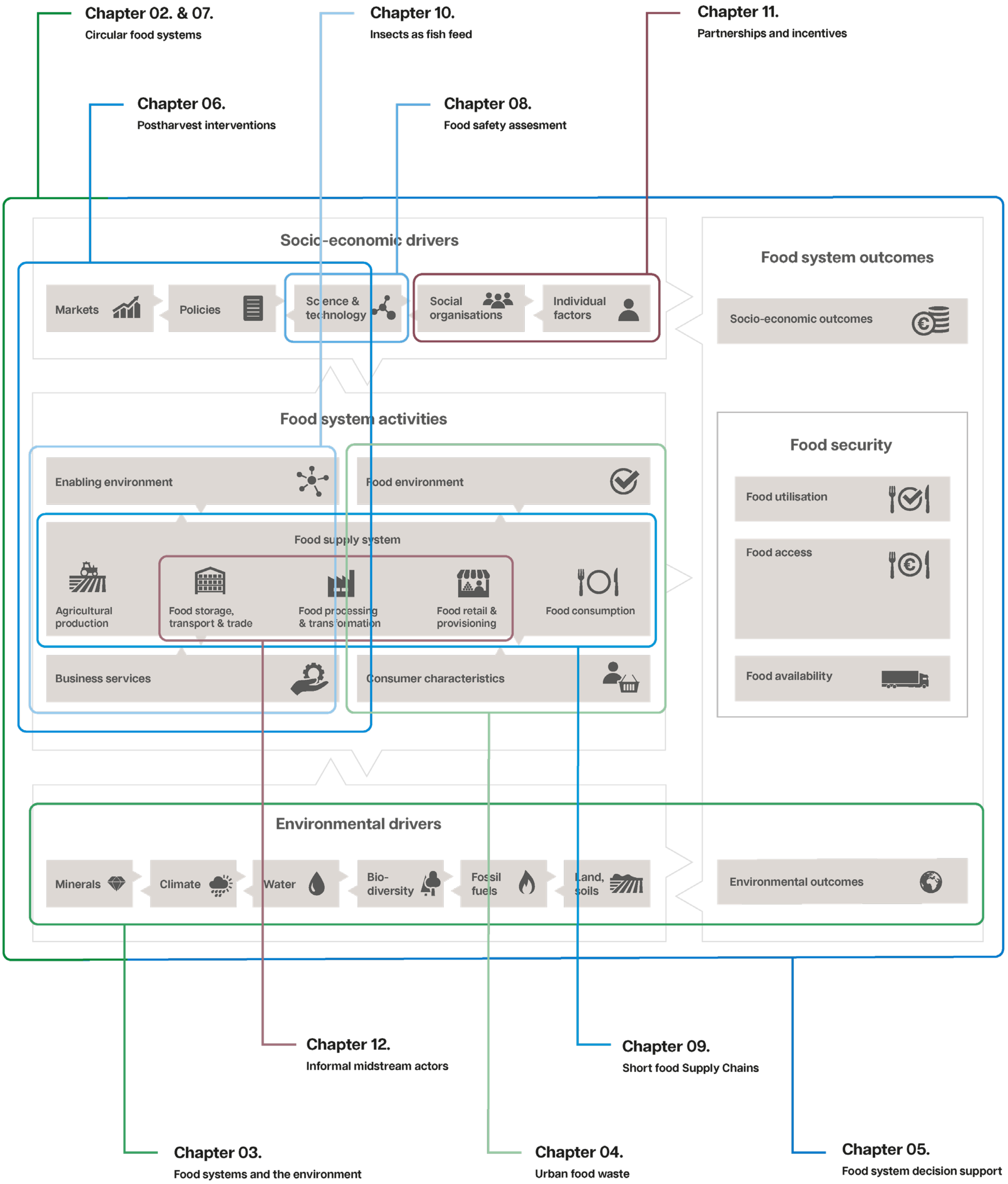

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Chapter 10.
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Chapter 11.
Partnerships and incentives
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Part A.

A systems perspective on Food Loss & Waste

Chapter 02.

Reconsidering inputs, reducing losses and recycling waste in circular agri-food systems

Siemen van Berkum and Ruerd Ruben

Regardless of how we technically define food loss and waste, significant losses and waste occur throughout our current agrifood systems, ranging from farm-level practices causing nutrient depletion, food value chains suffering post-harvest losses, and households and communities generating solid and liquid waste and human excreta. These losses and waste can be lessened if material flows can be shifted towards reducing, reusing and recycling; in other words, by transforming linear food systems into more circular ones. In addition, new technologies and biotechnology can advance this transformative shift through novel foods and fertilisers that lead food systems away from fossil fuel dependence.

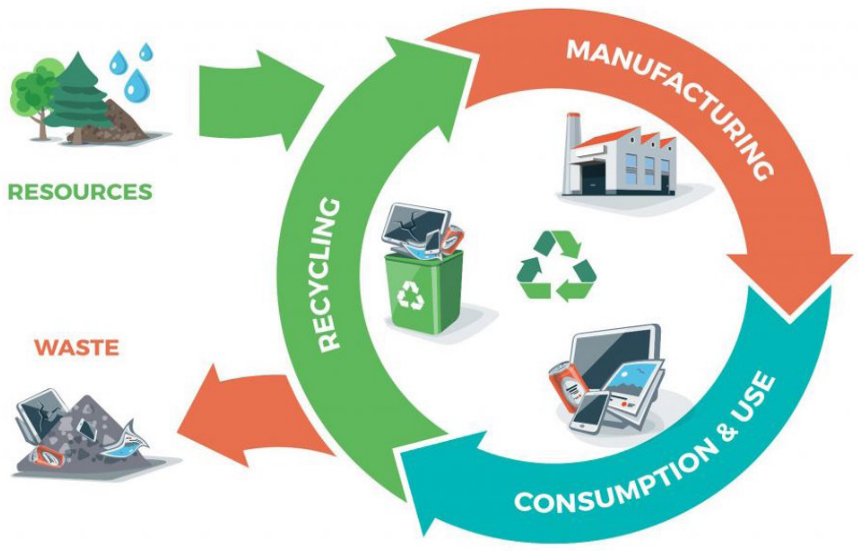

Figure 1. Circular economy principles for transforming food systems
Source: Nextstep. (retrieved from [Recycling Organic Waste | AFSEA])

Five key points are important to keep in mind when working toward circular food systems:

1. **Circular principles will make food systems not only more sustainable but also more efficient** – by increasing agricultural yields, by increasing food production and by adding value to agrifood chains.
2. **Supporting nutrient recycling opportunities at the farm, regional and national levels requires specific practices, programmes and policies** – specifically, those that enable substantial cost reduction, more diverse and resilient production systems and more efficient energy and water use.
3. **Interventions to reduce food losses at different stages of the food value chain vary by region, food group and value chain component** – yet they generally combine new technologies, better handling practices and supportive market incentives to improve productivity and food quality while reducing externalities.
4. **Household waste and human excreta can become important sources of nutrients and energy for improving food systems** – and can be recovered with community organization.
5. **Advances in developing a bio-based economy are promising** – these, too, can add to circular food systems.

How do we shift food systems towards circular resource use for sustainability and resilience?

Our society can be greener and more sustainable if we adopt measures aimed at reusing organic material from crops, aquatic biomass and residual flows produced in the agricultural sector. Circular food systems are based on the principle of optimising all biomass use. The waste streams of one supply chain can be the raw materials for another.

Circularity implies loss prevention, recovery for reuse, remanufacturing and recycling. The concept of circularity originates in industrial ecology, which aims to reduce resource consumption and emissions to the environment by closing the loops of materials and substances. In the food system, circularity is biophysical, and plant biomass is its basic unit. Farm animals are most effectively used to transform biomass that is inedible for humans into valuable food, manure and other ecosystem services. Moving towards biophysical circularity in the food system implies searching for practices and technology that:

- Rely as little as possible on the use of finite resources, such as land and phosphate rock.
- Encourage the use of regenerative resources, such as wind and solar energy.
- Prevent leakage from the food system of natural resources, such as nitrogen (N) phosphorus (P).
- Stimulate the reuse or recycling of resources that are inevitably lost – such as those in human excreta – in a way that adds the highest value to the food system.

Supporting nutrient recycling opportunities

The circular economy is highly dependent on the management of soils and land to perform basic functions, such as producing food and other biomass, and storing, filtering and transforming many substances including water, carbon, and nitrogen. As the human population grows, the demand for resources increases. Soil and land management are central to the circular economy – for maximising the reuse of resources and products, and for reducing resource depletion to a minimum.

> In assessing the circularity of farming systems, soil carbon and nutrient stock and flow analysis can help.

To reduce inorganic fertiliser purchases and to control emissions, natural nutrient cycles will have to be restored to agrifood systems. Restoring these cycles implies balancing stocks and flows of carbon and nutrients – N (nitrogen), P (phosphorus), K (potassium) – to support circularity and to enhance ecosystem services. Nutrient cycles can be restored at the farm scale, the (sub)regional scale or the national scale. Nutrient balances can be an indicator to determine nutrient use efficiency of farming systems. The analysis of nutrient balances is adopted as a way to assess the degree to which farming systems are circular.

Studies of plot and farm-level nutrient balances in sub-Saharan Africa reveal – almost unequivocally – alarming rates of carbon and nutrient depletion. Studies of high-production irrigated areas in Asia find that multiple cropping leads to fertiliser use and nutrient removal in crops at rates far exceeding those for rainfed agriculture; intensive production leads to environmental costs. The interaction between livestock, organic manure and the fate of crop residues is relevant in determining levels of circularity. Other mechanisms for increasing circularity are the reduction of atmospheric nitrogen emissions, erosion control and the reuse of human excreta.

> Using composting practices, green manure and household organic waste to improve soil fertility will reduce input purchases and enhance yields.

An alternative to manufacturing mineral fertilisers – which is energy-intensive and adds to greenhouse gas emissions – is to use organic fertilisers. One organic fertilising method is to include nitrogen-fixing species in farming systems – such as beans. Another method is to use compost from pits and heaps, or in integrating trees that root deep and bring up 'new' nutrients through leaf fall. Yet another organic fertilising method is manuring, which allows for integrated crop-livestock systems. This can take place at farm scale, where zero-grazing animals feed on crop residues and fodder crops, but it also occurs at larger 'system' scales: one example of this is in Sahelian West Africa, where pastoralist cattle often spend the night in rings around villages, fertilising them with their urine and faeces with nutrients obtained from the bushland farther away. After the growing season, abundant sorghum and millet residue production on these lands is then fed again to the animals. More generally, the recycling of crop residues in integrated crop-livestock systems can improve overall system performance, allowing 'preferred plot' manuring schemes for high-value crops.

Much is gained from the combined use of mineral and organic fertilisers. This combination often gives better production results than either fertiliser type by itself. In addition, the combination maintains better soil quality, expressed in the pH and organic carbon content. The challenge lies in ensuring that sufficient organic inputs are available at the farm level; at the same time, however, conducive policies are needed to take these farming systems to a higher level – that is, to environmental compensation, carbon credits, extension geared towards adopting green technologies, and so on.

Food loss and waste reduction priorities and interventions vary by region, food group and value chain component

Reducing food loss and waste is a major challenge in a circular economy – aiming at more efficient use of resources and recycling waste. Recent estimates by FAO (2019) show that worldwide, most losses occur in the product groups carrot, tubers and oil (25 per cent) and fruit and vegetables (20 per cent). In sub-Saharan Africa, losses of fruit and vegetables largely occur at the farmer's level during or immediately after harvesting, while in East and Southeast Asia the losses mainly occur during storage, packaging and processing. For meat and animal products, sub-Saharan Africa sees the greatest losses in the post-harvest, slaughter and storage phases. Globally most food wastage at food provisioning and consumer levels appears in developed countries. Based on these analyses, policy makers can prioritise and tailor interventions to help reduce losses at the most critical bottlenecks. For example, food losses at the farm level can be reduced by improving post-harvest operations, storage structures and packaging methods on the farm, by applying locally appropriate and affordable technologies.

Based on the principle that reducing food loss and waste 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 positively affect farmers' income and where fewer losses 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 the keys to success on the market, particularly for perishables.
- lacks evidence to adequately relate FLW interventions to measurable social, economic and environmental outcomes, that is, taking sufficient account of trade-offs and feedback loops in the food system.

Although these arguments provide general indications about which value chains to target for FLW reduction interventions – given particular environmental, nutritional or livelihood objectives – current literature lacks evidence to adequately relate FLW interventions to measurable social, economic and environmental outcomes, that is, taking sufficient account of trade-offs and feedback loops in the food system.

As these distinctions imply, the FLW chain contains producer-consumer trade-offs. For example, in low-income countries, reducing on-farm losses may have strong positive food security effects for consumers but not for all farmers by default. The loss reduction may especially benefit smallholder subsistence farmers by increasing the availability of food to them. But farmers who market part of their output may see drops in demand and price, with negative implications for their incomes and thus for their food security, as larger volumes cause prices to drop at later points in the supply chain. Such price drops benefit consumers.

Opportunities in household waste and human excreta recycling

Household residues consist of solid biological waste, liquid excreta, recyclable materials and non-biodegradable waste. Household waste and human excreta are important sources of nutrients and energy for improving food systems. Losses of these resources can be reduced with appropriate incentives and lost resources can be recovered with sound community organisation.

Household food waste is mainly a result of consumer behaviour related to food buying, preparation and storage. Reducing household food waste requires integrated food management that includes shopping, storing (including cold storage) and appropriate cooking and eating practices. Awareness and educational campaigns can provide incentives for household food waste reduction.

A wide range of technological opportunities and innovation strategies are available to better link the producers of waste and excreta in urban and peri-urban households to the potential users of recycled products in rural and urban livelihoods. Waste and excreta can be used for different purposes, ranging from energy (cooking and heating) to the organic fertilisation of homestead vegetable production.

Recycling and reusing household residues requires efficiently organised recollection and treatment processes at the neighbourhood and village level in order to guarantee volume (scale), velocity and safety. Africa currently recycles only four per cent of its waste, and more than ninety per cent is disposed of in uncontrolled dumpsites and landfills. In Asia, much of the recollection is done by local associations, whereas in larger agglomerations publicly organised municipal waste services are in charge. Literature shows that the main opportunities for tackling food waste include: production.

- Sharing information and knowledge across stakeholders, for instance about hygiene and freshness of food, and insight into food purchasing behaviour.
- Broad legislation for reusable and/or biodegradable packaging.
- Circular, rather than linear, solutions for food waste reduction that rely on multi-stakeholder collaboration – especially public-private partnerships.

The promise of biobased solutions

Recent innovations suggest that feedstocks for biobased products can be produced from renewable or recycled raw materials – biomass, waste, CO_2, and so on – rather than from fossil fuels. Examples are the offshore cultivation of seaweed for the production of biogas (for electricity and heat production) and proteins and algae-based biopolymers that can replace conventional petroleum-based polymers and (other) plant-based materials used for packaging, food service items and biofuels.
Such a green shift in biobased products could alleviate economic, ecological, and societal problems worldwide. The promise of biobased solutions lies in:

- Replacing fossil fuel-driven production with circular systems based on biological sources, leading to vast environmental benefits and employment opportunities.
- Introducing untapped resources into the food chain, relieving pressure on existing food systems.
- Producing materials that, being biodegradable, will never be 'wasted' for environmental use.

Although knowledge is growing on how biotechnology applications can support circular food and energy systems, significant research and development, as well as further investments will be needed to make the technology ready to use.

Policy priorities for circular agrifood systems

To shape the transition to circular agrifood systems and support the biobased economy, policy makers must focus on developing and promoting technologies, resource use practices and policy incentives that enable stakeholders to reduce, reuse and recycle food losses, waste and residues in order to enhance the efficiency, sustainability and diversity of food systems. Specifically, policy makers should:

1. **Support nutrient recycling in production and food systems** with knowledge development, innovation programmes and market support measures.
2. **Reduce food losses based on the intended food system outcome**, on product group and value chain segment, by combining focussed technical interventions with increased services for agrologistics, finance and training, bearing in mind though that the evidence base is still shaky.
3. **Enable waste recovery from food and excreta in households and neighbourhoods** through the combination of awareness raising, public or private recollection services and behaviour change incentives, within the boundaries of food safety and public health.

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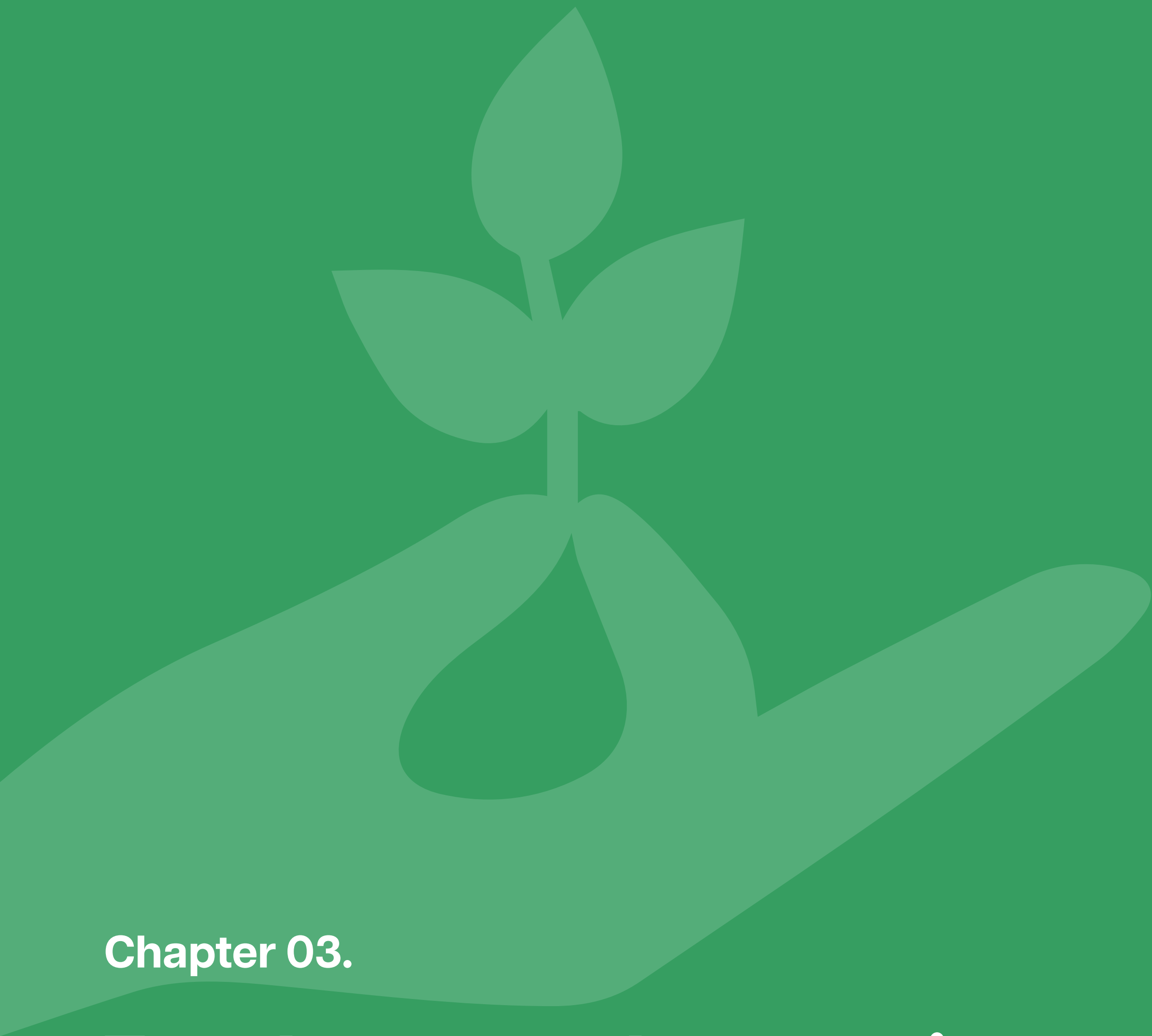

Chapter 03.

Food loss and waste in a changing environment

Bertram de Rooij, Arjan Koomen and Xuezhen Guo

The relationship between food loss and waste and the environment is a domain that is still understudied and often overlooked. However, placing food loss and waste in a changing environment will open opportunities to deliver valuable new insights and better tailored and targeted interventions. Most of all, it will contribute to a more effective outreach to stakeholders and society.

In this chapter we will delve into the way(s) food losses and waste link to a changing environment and we thereby address three key messages:

- **do not wait for the future to happen**
- **the uptake of a spatial approach: close to home or a distant reality**
- **work on positive stories that connect and inspire to action**

A changing environment

Food loss and waste (FLW) puts a direct, but not always felt, burden on our natural resources and environment; think about land, water and air. Reducing FLW will limit the adverse effects on these resources and conditions, but how exactly this works is highly dependent on many factors – factors that are not limited solely to the physical environment, but rather that interact differently along the food supply chain and across a diverse range of food system activities. The food system is already highly complex, even before we examine it in relation to its environment. We define the environment in the broadest sense: Of course, it is all about the physical environment, the natural conditions and processes that form the fundament for our food system, but at the same time it is strongly affected by this system. It also directly and indirectly links to how these physical influences manifest, and is at the same time influenced by the socio-cultural, socio-economic, and political environment. These cannot be seen as separate; a complex, dual or even reciprocal complex reality emerges.

Nonetheless, within this complexity the environmental and spatial lens also provides an opportunity to make issues, challenges, and interventions more specific, tangible, and attainable. The environment is most recognisable and near, but changes rapidly. Change is often reinforced by linked processes. Climate change and urbanisation are among the biggest drivers of change in the world as we know it, putting pressure on the natural systems and resources and, together with practices that are not environmentally sustainable, triggering even more rural-urban migration. Urbanisation and the food system amplify climate change, but at the same time both rely on the limited and valuable natural resources in the environment, which they are impacting even more. FLW plays a significant role in this. Imagine; what would a 10% reduction of FLW mean for reducing pressure on resources and the environment? Some even refer to FLW reduction as one of the most promising solutions to limiting climate change, such as Project Drawdown. But how big is the impact? Where does it link?

FLW manifests in different ways and at different places and stages in the food chain. It differs across regions, as do the direct and indirect effects. The Global North deals with mostly waste closer 'to the plate' (consumers and retailers), whereas the Global South is challenged in the first stages of the chain, closer to the farm (post-harvest, processing and distribution). These different manifestations require different strategies, but these strategies always rely on collaboration across the supply chain and with a broad field of stakeholders. If we observe the current strategies and science, we see an impressive overview of numbers and graphs on actual FLW and its potential impacts. But it that enough? And do they sufficiently take into account the changing environment?

It is of utmost importance to understand these relationships and opportunities much better and change strategies with the environment as enabler: not only solving the problems of today, but preventing future losses and waste while fostering a systemic change.

Do not wait for the future to happen, climate change is happening as we speak

The world is already changing rapidly – climate change and the need for adaptation is already eminent. Agricultural production is already affected by climate change, although the impact differs highly between regions. The risk of loss and waste due to extreme events has increased and climate zones are gradually changing. This requires immediate action to adapt, otherwise FLW in the beginning of the chain will rise substantially. As it stands, climatic changes will have an impact in the next steps in the chain as well. What to think about the increased need for cold chain applications for fresh products and the effects on the energy demand and the adverse effect this has on greenhouse gas emissions? At the same time, this paves the way to alternatives like improved processing industries that not only benefit local economies but also prevent food loss and waste.

Unfortunately, much of the FLW data is still based on the past and present situation and models incorporating the realities of today. This quantification is a difficult exercise with large uncertainties and therefore often ends up with a high level of aggregation, and yet it remains bound to the current situation. This raises the question whether one should take a more forward-looking approach, or rather a more spatial approach that is not time-bound and would thus also apply in the future?

Both a spatial approach as well as a forward-looking approach would contribute to new knowledge and insights in comparison to FLW as it is currently generally being elaborated. We therefore advocate for an integrated spatial approach in which we look at the natural system (soil, water, biodiversity), the socio-cultural system and the chains coherently. We find that answering the 'where' question is crucial insofar as the actual field of action is integral to the source of knowledge. That is not to say that this is the 'best' way forward, but rather that it is missing in current FLW thinking and can serve as a more specific springboard to environmental and climatic issues that are often geographically determined. Even in time, this spatial differentiation does matter and is helpful. Using a forward-looking lens on a spatial perspective helps to make solutions and strategies to reduce FLW more plausible, near and imaginable. We are convinced that combining the spatial and integral dimensions with the time dimension will lead to new angles and perceptions – paving the way for new, sustainable solutions as well as adding to the narrative on FLW.

To begin with, linking chain parameters and climate change parameters could serve to move towards more integrated decision support tools and approaches. There are already several useful studies and support systems available that could help us to get a better grasp on what the effects of climate change can be on agricultural production and the food chain. We need to use and enhance reliable forecasting tools that project the impact in different regions. Good examples are the "Copernicus Climate Indicators for Agriculture" (CCIA), CGIAR CCFAS and the climate atlases, but we are convinced there is much more potential in linking models that are still overlooked. We would like to challenge each other to explore and operationalise this. CCIA developed a set of operational services with high-impact climate derived information aimed at the agricultural and food sector to make informed decisions. End-users are involved and proven state-of-the art technologies on earth observation are combined with crop modelling. We should strive to harness data and insights from these services to assess what the impact of FLW is in the beginning of the chain.

The CGIAR CCFAS project estimates the total required investment costs for a successful climate smart agriculture transition based on forecasting. It considers what is needed to prevent detrimental impact and should also include the potential avoided costs of FLW and the net effects on available resources and geographical variation. Moreover, a greenhouse gas emissions calculator was developed to calculate emissions along the food chain. This informs decisions and facilitates a quick recalculation of the FLW footprint across the value chain and at different spatial levels.

Inspiration on how to comprehensibly present the full FLW story in a new and different way can be found in the climate community. The **climate effect atlas** and **climate damage atlas**, for example, are proven combined decision support systems and valuable communication tools. Not only through clear mapping (visualisation), but especially with clear storylines and narratives, they guide the professional and non-professional user through the why, the what, the where and the different hows. Like climate change adaptation, one must not rely upon one single strategy, but use flexible strategies at different levels and places, to best be able to deal with the various realities as well as uncertainties.

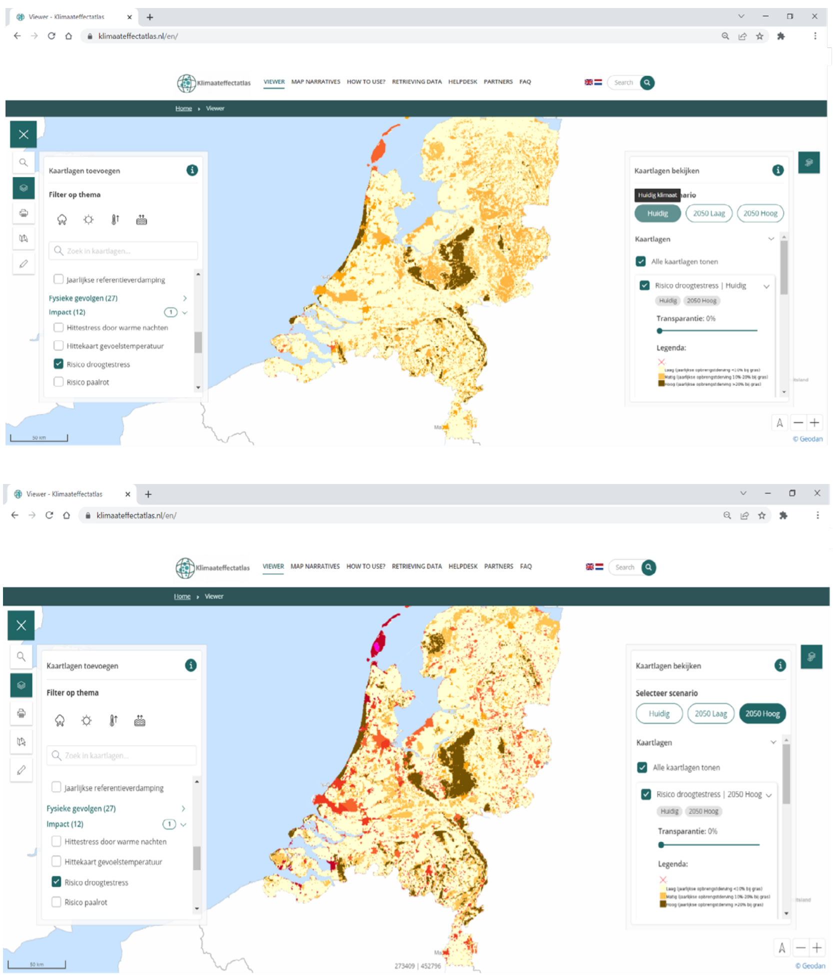

Figure 2. Example from Climate Effect Atlas: risk drought stress current versus 2050 (source Climate Effect Atlas, CAS)

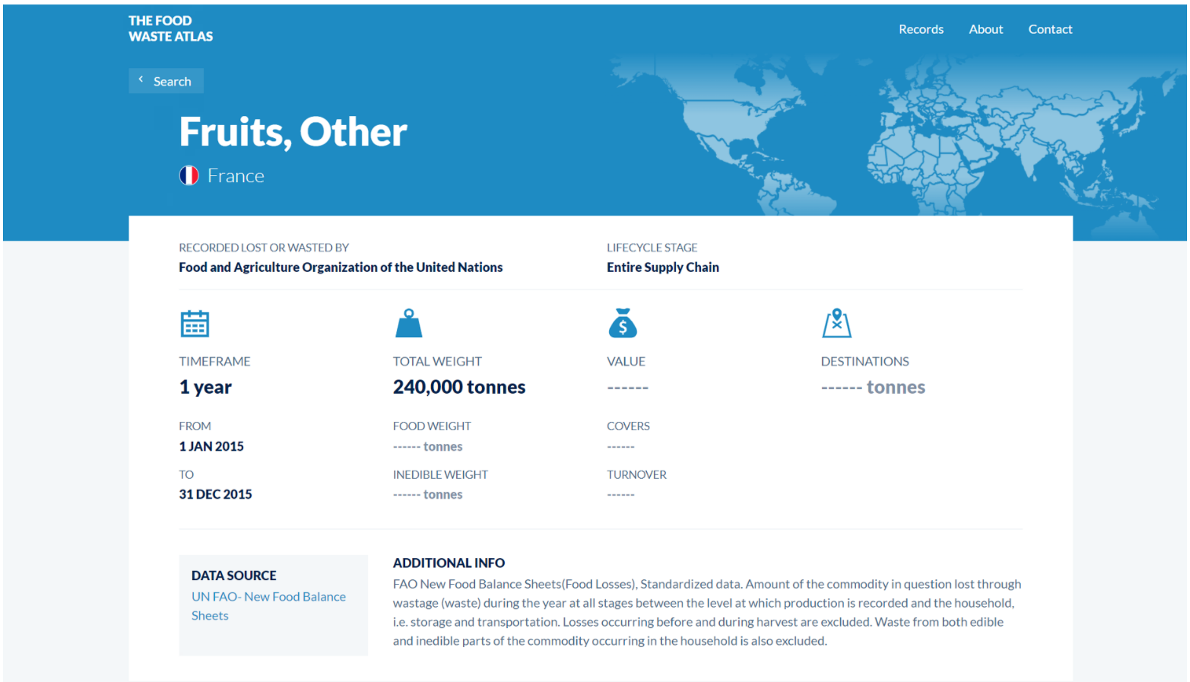

Figure 3. Example: Food Waste Atlas (**thefoodwasteatlas.org**)

The uptake of a spatial approach: close to home or a distant reality?

To effectuate lasting changes, one needs to build momentum through compelling stories. This momentum should be fundamentally linked to the actual people that can make the change happen, which implies that we must reach out to the public and make FLW more visible, understandable, and recognisable at the local and regional levels. Information providing more spatial detail helps in these narratives, offering more possible action perspectives and a better connection with society.
FLW interventions along the chain require different strategies and actions due to the highly variable contexts in different regions. FLW reduction therefore asks for a regional and tailored approach, which in turn requires different knowledge and insights that should be gathered across domains. There is a vast amount of environmental knowledge and sustainability that is currently not linked to FLW reduction efforts. Introducing this specific issue in these processes and linking knowledge would lead to a more comprehensive picture of FLW and generate new perspectives.

Much of the data and information about FLW remains global, or if we are lucky, at the country level. To obtain within-country distribution and a more spatially defined strategy and action, we need to get more local governments and stakeholders at the table to establish new data collection networks on regional or local scales. For example, the city of Amsterdam works on developing a FLW monitor in the Amsterdam Metropolitan Area.

Current FLW data collection is costly and often not perceived as core business for many players along the food chain. This calls for smarter and cheaper data collection methods or ways of providing incentives and links to actors' primary motives.

It's the development of simple, user-friendly IT solutions and the clever utilization of existing data are the keys to proceeding into our collective future in a smarter, cheaper, and more innovative way. Some examples are analysing data of companies' waste collection and separating food waste into different streams, using a drone to detect food losses on farms, or using cameras to detect food waste in restaurants. A great example is the user-friendly data collection systems developed by the UK Waste & Resources Action Program (WRAP).

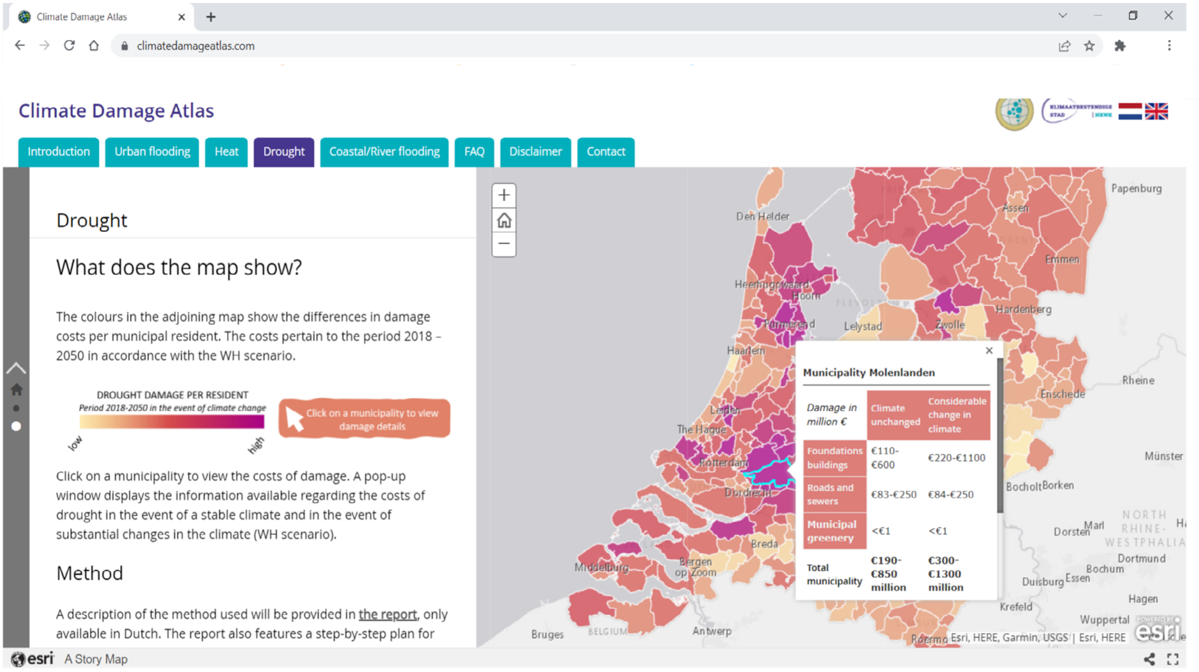

Figure 4. Example: Climate Damage Atlas: cost estimations per municipality, current situation versus changed climate, including storyline (source Climate Damage Atlas, CAS)

Work on positive stories that connect and inspire to action

Much of the work on FLW appeals to our morals, providing incentives to minimise our detrimental actions. Flipping the story to a positive one is a game changer, entailing not only explaining the problem, but calling on us to act in ways that benefit all, regardless which motive. In addition to the spatial approach and the importance of a future perspective, FLW should be better integrated in the different development processes along the chain and in a given region. We highlight some inspirational examples.

The vision Food Connects 2050 provides a holistic view on the Greater Washington metropolitan area based on the food system perspective. It interlinks different scales, values, and interventions. The so-called 'food hubs' that are at the heart of the communities are key to this vision. It inspires a call for action on the part of different actors at different levels: local to global, global to local, the availability of good food represents a desirable future for all. The future studies of FLW are integral to this vision.

The Green Circle initiative 'Tuin van Holland' brings together stakeholders along a value chain in the broadest sense. Different actions to simultaneously improve both the chain and the environment are developed through a programmatic approach based on shared understanding, shared actions, and shared ambitions. Its interesting projects are dedicated to looking at possibilities for the sustainable production of healthy food and prevention of FLW.

The future is now

To conclude, the future is now. We should aim not so much at having less of a detrimental impact, but rather at doing things differently – opening our view to our changing environment and proactively meeting the challenges it presents. Taking up FLW through both environmental and spatial strategies is a real game changer, and it starts with inspiration and envisioning a better future.

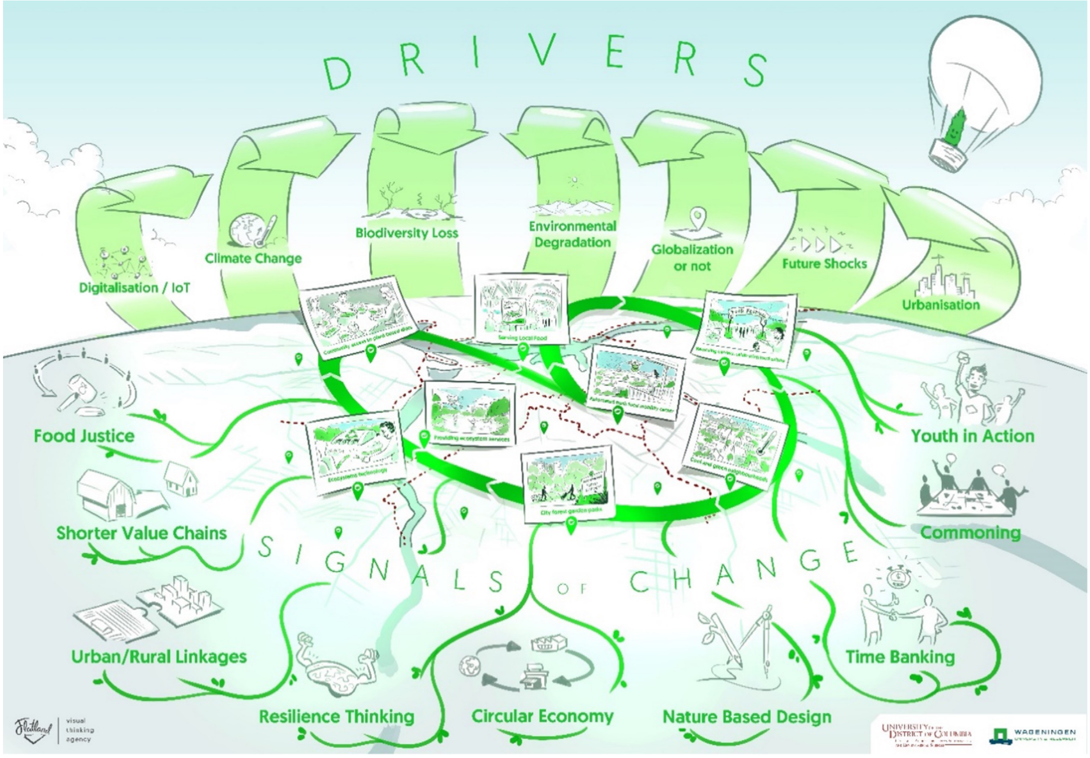

Figure 5. Food connects 2050 (source: WUR/Flatland, 2020)

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For inspiration

https://www.greencircles.nl/
https://www.rockefellerfoundation.org/blog/cities-of-the-future-envisioning-better-urban-food-systems-in-2050/
https://climatedamageatlas.com/

Chapter 04.

Food loss and waste in cities

Michele Pedrotti & Daniele Fattibene

With cities being a key player in the current food systems, reducing and preventing urban food waste is essential to facilitate the transition towards more sustainable and circular food systems.

Addressing food waste in an urbanising world

Over the last decades cities have progressively come to the fore as new, crucial actors in the global and local food security geography. As of today, cities host more than half of the global population and they are at the core of some of the deepest food security-related transformations and contradictions, especially if we consider that over 68% of the world's population is expected to live in urban centres by 2050. The main reasons behind this demographic transformation are population growth and the mass migration from rural to urban areas. These trends are occurring simultaneously, mostly in developing countries, and they are posing immense food security challenges not only in terms of access to nutritious food, but also in terms of food waste (FW) management. Africa and Asia are at the forefront of these developments, experiencing a rapidly growing population with a projected increase of 42% and 12% respectively over the coming 15 years. It has been calculated that about 70% of all food produced is destined for urban consumption and that cities are responsible for over 75% of natural resources consumption and at the same time, over 50% of global waste production (FAO, 2017). FW is thus a global problem, with around 121 kilograms per capita generated every year at the household, retail and food services levels. Given that the population tends to be concentrated in urban settlements, cities are generating most of this waste. For instance, cities like Los Angeles are producing up to 800,000 tonnes of edible FW every year (Los Angeles Food Policy Council, 2013), whereas in Bangladesh, from 68% to 81% of the total municipal solid waste is composed of FW, with Dhaka, its capital, producing about 1.2 megatonnes of FW every year (Ananno et al. 2021). Cities are therefore the first place where effective FW prevention and reduction strategies need to be realised (Dubbeling et al. 2016).

The interest in the environmental and economic damage caused by urban FW has led to a growing political and public consensus to address this challenge. Local and national institutions, businesses, researchers and non-profit organisations have started to invest in policies, measures and campaigns to reduce and reuse the FW generated across the chain from farm to landfill. For example, the European Commission recently included FW as an integral part of a comprehensive strategy to achieve a circular economy. This has resulted in the adoption of a common definition of the phenomenon as well as legislative measures to ease bureaucratic burdens for food donations and start a proper monitoring of countries' performances. At the national level, several countries like France and Italy have pioneered in this process, rolling out innovative legislation to tackle FW at the retail and consumer levels.

Although cities have proved to be a crucial actor in food systems' transformation, current urban FW research still suffers from a lack of scientific literature on the topic. While we are witnessing the emergence of several frameworks, definitions and approaches, there is still a very limited number of peer-reviewed studies that have tried to assess effective urban FW policies. Moreover, FW management still plays a minor role in urban planning, and this makes it harder to identify hotspots of FW generation, as well as to design, implement and monitor urban food policies.

A three-step approach to tackle food waste at the city level

Tackling FW at the urban level requires a three-step approach based on i) an accurate mapping of FW generation hotspots, ii) the design of effective monitoring schemes and iii) the launch of proper urban FW policies and/or initiatives. In addition, given the lack of a one-size-fits-all approach, effective urban FW management needs to be context-specific and tailored to local needs. These steps are a condition sine qua non to achieve a series of goals such as (i) identifying the right food system actors while assessing FW reduction at all stages of the local food supply chain; (ii) raising awareness of FW through targeted events, campaigns and education; (iii) collaborating to develop and review municipal policies and regulation to prevent waste or safely recover food and packaging using a "food-use-not-waste" hierarchy; and (iv) facilitating recovery and redistribution for human consumption of safe and nutritious foods.

Although this approach might seem easy to follow in theory, practice and experience tells us that very few cities have the human, financial and technical resources to achieve these goals. This is particularly true for cities in developing regions, where reduced budgets limit the possibility to undertake comprehensive analyses of the FW hotspots and related measures. This complexity has been further exacerbated by Covid-19, with a recent survey by FAO highlighting that cities in the developing world have needed to tighten financial resources, and have thus had fewer tools at their disposal to address effective food policies interventions (FAO, 2020).

Chasing FW generation hotspots is still a challenging task for at least two main reasons. On the one hand, local governments lack the technical, financial and human capabilities to undertake comprehensive analyses and collect data on FW levels within their boundaries. On the other hand, even when these resources are available, assessing urban FW proves to be challenging for local decision-makers. The fight against FW at the urban level can be conducted by a wide plethora of actors (e.g. public institutions, private actors, civil society organisations) whose actions do not necessarily fall within the control of public authorities and are not easy to coordinate.

Identifying food waste hotspots

Understanding what the main FW hotspots in a city are is a complex task. City mayors and local governments usually have a limited understanding of urban food chains, and this is reflected in a dramatic lack of data and information about the urban metabolism. Moreover, cities usually have completely different situations depending on the demography, the geography and the socio-economic environments in which they are interacting. This means that while for some cities FW hotspots may be located in particular layers of the food supply chain, for others these trends could be different. A particular relevant difference to keep in mind is the one between high-income and low- or medium-income countries (LMIC).

As for high-income countries, a recent study conducted on 22 cities in the United States by the Natural Resources Defense Council (NRDC) has shown (Figure 1) that around two-thirds of FW at the urban level is generated by households (37%) as well as by restaurants and caterers (27%). If we add food manufacturers and processors (accounting for 14% of total FW), this figure reaches 78% of total FW. A more limited portion of FW was linked to food wholesalers and distributors (5%), grocers and markets (5%), hospitality (4%), and health care (2%). While these figures may differ a lot, depending on the sample analysed, they are important insofar that they may serve as a starting point for local policy makers designing and implementing the best strategies to address FW. In fact, the study estimates that the 22 cities analysed had a potential of 73,000 tonnes of reusable food per year. While this study offers an initial important starting point, the authors are aware of the enormous logistical challenges of food rescue—including transportation from food businesses to redistribution sites, adequate cold storage capacity, shelf-life concerns from some sectors, and current low participation in donation from many types of food businesses. These complexities are even greater for cities in LMICs, where the retail and distribution sectors are dominated by informal activities. A study in Dhaka, estimated that around 200,000 street food vendors are essential for the food security of over eight million people a day, which is more than half of the city's population (Khairuzzaman *et al*. 2019).

Developing effective monitoring metrics

After having determined where the major FW hotspots are for a specific product in the urban food supply chain, it is time to implement a FW reduction or prevention intervention at these stages. When designing and implementing such an action, it is fundamental to evaluate the intervention in a systematic manner by using a framework with standardised definitions and measurement methods, and by ensuring the evaluation of long-term effectiveness. However, there is still a knowledge gap in terms of a common evaluation framework for such purpose. In Europe different attempts have been made to establish such a framework. Among the most successful projects are the FUSIONS and its follow-up, the REFRESH

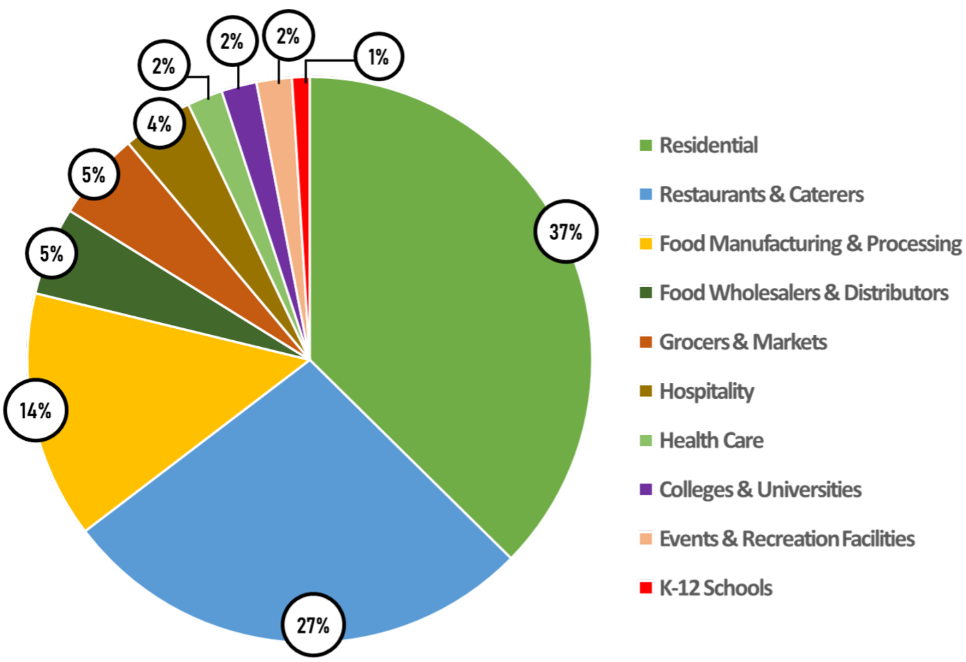

Figure 6. Average distribution of FW generation by sector across all cities (adapted from NRDC 2021)

1) See **https://www.nrdc.org/resources/feeding-city-food-waste-and-food-need-across-america**

Figure 7. Designing an Urban Food Waste Framework. Source: Fattibene et al (2020)

project, which provided a definitional framework for FW together with a manual for FW quantification. Moreover, the European Commission Joint Research Centre has developed an evaluation framework for FW prevention actions together with a FW prevention calculator to assess the benefits of a FW prevention initiative from both an environmental and economic perspective. These first attempts are essential to guarantee that policymakers and stakeholders across the supply chain can access tools to standardize the effort in reducing FW. In this way, it will be possible to evaluate different interventions and select the ones that proved to perform better in terms of reducing FW, and providing more benefits in terms of economic, environmental and social value. These tools can also be applied to urban realities that are different from the European context, like cities in LMIC. Modifications should be made by taking into account the specific urban scenario and supply chain. For example, logistic and resource limitations or the impossibility to access high-level technologies may prevent the adoption of FW prevention actions that proved to be effective for European cities.

Designing urban food waste policies

The last step is to design effective urban FW policies. To do this, local policy makers should take into account three main issues. First, they need to be aware that several types of FW policies, projects or initiatives can be activated at the local level. Second, decision-makers have at their disposal a broad range of intervention areas that can be directly or indirectly managed by mayors (e.g. food donations, education campaigns, fiscal incentives). Finally, urban FW initiatives can involve a very wide range of actors, including public authorities, school canteens, food markets, retailers, consumers, charities, etc. Figure 2 attempts to visualize such complexity and to provide cities with a guidance to ensure that their policies are aware of the rich ecosystems present in urban realities.

In the last decade, cities' networks and alliances such as the Milan Urban Food Policy Pact (MUFPP), C40, ICLEI and EUROCITIES are playing a key role in sharing best practices and lessons learnt, which will be replicable and scalable to different global contexts. Since 2015, the MUFPP has gathered more than 370 innovative and effective urban projects and initiatives. Moreover, the MUFPP has partnered with FAO to develop a Monitoring Framework consisting of a series of 44 indicators and a Handbook and Resource Pack aimed at helping local decision makers to effectively assess food systems performances at the city level, including FW management. A recent report has shared the results achieved through a series of pilot projects conducted in three cities in 2019 in Madagascar (Antananarivo), Kenya (Nairobi) and Ecuador (Quito) (Carey & Cook, 2021).

The experience of these cities networks and alliances confirms that cities with structural integrated urban food policies are better suited to roll out effective anti-food waste initiatives. This has been even more evident in the first wave of Covid-19. A recent survey led by FAO has shown that global cities have paid the highest price in terms of food insecurity due for instance to the closure of food markets and school canteens, with the most dramatic consequences suffered by the most marginal groups of the populations, such as women, informal workers, children and the elderly (FAO, 2020). However, the pandemic has also demonstrated that cities have set up innovative responses (FAO, 2020) to the emergency, and that cities with integrated urban food policies reacted faster to the crisis. In Bandung (Indonesia), FW is leading to huge environmental and economic costs, as it represents more than 55% of total urban waste generation. During the first wave of the pandemic, the city launched a programme called "Zero Waste regions" that involved more than 140 local communities transforming FW into compost to be used for urban gardens to produce fresh fruits and vegetables.

Urban food policies to fully unlock the sustainability agenda

Given the current demographic trends, cities will play an increasingly key role in global food systems and in related sustainability strategies. Reducing urban FW should be among the priorities of all municipalities, since it can help in tackling both food security and environmental issues, including FW management challenges. The three-step approach presented in this chapter is one of the possible strategies that could help cities in this direction. Urban food policies, by also facilitating actors' cooperation, can help in the achievement of different Sustainable Development Goals from the Agenda 2030. Cities need the proper technical and human resources to evaluate FW generation magnitude and design effective actions to push all actors in the metropolitan food chain towards a truly coordinated anti-food waste revolution. There is no more time to… waste.

2) See also: **https://covidnews.eurocities.eu/**

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Part B.

Intervention strategies

Chapter 05.

How to make food system-informed choices to reduce food losses and waste

Herman Brouwer & Helena Posthumus

Policy makers and researchers who try to address food loss and waste increasingly call for a food systems lens to be applied in order to select the best intervention pathways. Putting this into practice, however, is not easy. The Food System Decision Support Toolbox offers guidance to conduct a food system analysis with the participation of a diversity of chain actors, leading to actionable recommendations.

How to make food system-informed choices to reduce food loss and waste

Imagine you are tasked to develop new interventions to fight food loss and food waste. There are many elements to consider: which supply chain, which context, which market system, which stakeholders are holding influence, which levels and scales to focus on, and so on. The sheer number of choices to be made is dizzying. Food is involved in so many aspects of life, and so many business sectors, and so many scientific disciplines – where to start?

Fast forward... and imagine that you want to implement some of the interventions that seem most promising. How will you convince others that these interventions are the right ones? How do you get people on board to give it a try, and collaborate to find solutions? If you are a scientist, perhaps you have been taught that you just provide the evidence and it is up to others to decide and implement. If you are an entrepreneur or policy maker, you will recognise that a brilliant scientific analysis will not automatically lead to buy-in and action from stakeholders.

This article aims to give you practical suggestions on how to deal with the two dilemmas above: how to do a 'good enough' food system analysis that will help you make choices regarding food loss and waste (FLW) interventions, and how to do this in a way that increases stakeholder ownership over the results of this analysis.

A longer and practical elaboration of the approach described below is available as the **Food Systems Decision Support Toolbox** (2021).

Working with systems: a cookbook rather than a recipe

If you try to make sense of a complex adaptive system (such as a food system), a step-by-step recipe for a food system analysis will not work. The food systems in which food losses and waste play out are too dynamic and context-specific to allow for a fixed approach. Instead of a recipe, the Food Systems Decision Support Toolbox is a cookbook that aims to inspire anyone with an interest in food losses and waste to get involved in food system analysis and learn how to tailor this to the context, regardless of whether you are a policy maker, practitioner, or researcher. It helps to make informed strategic decisions on the design of policies or interventions in the domain of food loss and waste. After all, any systemic change needed to address food loss and waste is going to affect the larger food system. Therefore, it is critical that you develop a basic understanding of the food system so that you can identify the best entry points for change.

It is important to realise that a food system is not a static entity, but a dynamic system. Change one element, and the whole system changes. Changes will set things in motion: a new technology for mobile cooling will enable the food system to reduce food loss, but it could, in turn, also cause smallholder farmers or small entrepreneurs to miss the boat because they cannot access capital to invest in these new mobile coolers. A small change in technology can have unexpected knock-on effects that will alter the outcomes of the food system. This is a key characteristic of a dynamic and interconnected system. A food system analysis therefore needs to take this dynamism into account, and go beyond a snapshot analysis of the current situation, by also looking at system behaviour and longer-term trends.

Doing a food system analysis: the process

Conducting a food system analysis that can be used to formulate recommendations for policy and programming requires the following building blocks (Figure 8):

Moving from the left to the right, you will notice that a food system analysis always starts with the question 'why'. Even if we zoom in on food losses and waste as an element of a particular food system, it is necessary to be specific about the type of outcomes you wish to see (socioeconomic outcomes, food and nutrition security (FNS) outcomes and environmental outcomes), the system's boundaries, and target groups.

Food and nutrition security outcomes:
FNS is often the starting point for a food system analysis. Understanding the dynamics around FNS for different social groups will guide the further analysis. FNS is a result of the availability, accessibility (including affordability), utilisation and stability of food. This includes for example consumption patterns, nutritional value of diets, food safety, market infrastructures, the production, storage and trade of food and the seasonal fluctuation of food availability. An objective related to FNS outcomes to which FLW interventions can contribute could be improve the availability and supply stability of food.

Socio-economic outcomes:
A food system results in socio-economic outcomes such as health, employment and wealth, but also incomes and living conditions of specific target groups. It is evident that the agri-food sector is a major shaper of a country's economy and societal wellbeing. A large share of households worldwide find employment in agriculture and food – ranging from subsistence farming to industrial food production. Furthermore, the way a food system behaves and the rules of the game influence who benefits, and who loses out. This affects poverty levels and the level of equality between citizens. Given that we are aiming to

Policy Objectives

The starting point of any analysis is the broader policy goal or question that will be addressed, including the level of intervention and/or target group. It is the answer to the question: 'Why this food system analysis?' The goal defines the direction and boundaries of the food system analysis.

Food System Actors

System actors entail every individual, group and organisation that is somehow involved in, or affected by, the food system. With their actions and interactions they shape, reshape or block the food system. Identifying the interests and influence of different actors, and the underlying power dynamics and structures, helps to inform your engagement strategies.

Food System Characteristics

A food system has many different elements, including drivers, activities and outcomes. To get insight, one needs to understand the trends of these components on the basis of key indicators, as well as synergies and trade-offs between them.

Food System Behaviour

The different elements within a food system do not act independently. As elements interact, systems reveal patterns of behaviour that determine the outcomes. Examining causal relationships make it easier to understand system behaviour, and to identify leverage points for system change.

Recommendations

This final stage explores the space for potential interventions directed at the leverage points. The findings of the food system analysis are combined to formulate actionable recommendations.

Figure 8. Food system analysis process (Posthumus et al. 2021)

transform food systems so that they work for the majority of people, it is essential to have a grasp of the socio-economic outcomes of a food system. An objective related to socio-economic outcomes to which FLW interventions can contribute could be to increase household incomes.

Environmental outcomes:

Activities in food systems often compete for common natural resources that are threatened by human activity. The role of agriculture and food consumption in damaging our planetary health is widely recognised. Any transition towards sustainable food systems is not only about producing nutritious food and supporting livelihoods but also about dealing with environmental degradation and climate change. A food system analysis should look for pathways towards more regenerative and sustainable food system outcomes. An objective related to environmental outcomes to which FLW interventions can contribute could be to prevent water pollution.

System boundaries:

A food system is hardly ever bound to a specific geographical area. Furthermore, a food system is also embedded in, and impacted by, other human or natural systems, so in reality, it is impossible to draw a clear line where a food system starts and ends. Nevertheless, it is important to choose system boundaries (for example, based on geography, outcomes, and target groups) for the food system analysis to maintain focus. When choosing the system boundaries, the goal of the food system analysis should be leading. An example of a goal relevant to food losses and waste, is the 'identification of FLW interventions that effectively contribute to various food system outcomes' in a specific geographical area or commodity chain. Of course, available resources, such as financing and time, also need to be considered.

Target groups and diversity:

Food system outcomes are never the same for different groups in a society. Hence, the objective may refer to a specific target group (such as micro-entrepreneurs in cold chains). If this is the case, it should become a focus point in the food system analysis. Even if there is no specific target group, it is still important to take into account social diversity as policies and interventions are never neutral; they have inherently different effects on different social groups.

Three analytical components of a food system analysis

The toolbox is divided into three analytical components: system characteristics, system behaviour and system actors. These three components combined will provide the insights to address the formulated objective and inform a policy design or intervention strategy. Depending on the existing knowledge of the food system and the specific food loss and waste issues to be addressed, some parts of the toolbox may be more relevant than others.

1. System actors

How a food system operates depends largely on the actors involved. System actors can include every individual, group and organisation that is somehow involved in the food system. Through their actions and interactions with each other they shape and reshape the food system, or cause inactivity or stasis in the food system. For a good understanding of the food system, it is therefore key to understand who the actors are, how they act and interact, and why they do so. Hence, this component starts with defining the actors and their sphere of influence. A food system is rarely a level playing field; power dynamics shape the interactions between these different actors. We therefore recommend doing a political economy and governance analysis towards the end of the food system analysis. This provides an overview of the power dynamics in the food system: who benefits and who is excluded across different social axes of privilege/marginalisation, including insight into one's own position.

2. System characteristics

This component aims to create an overview of the issues to be addressed and the current status of the various elements of the food system. A food system analysis seeks to understand the problem as defined in the objective; in other words, exploring the dynamics of the socio-economic outcomes, food and nutrition security outcomes and the environmental outcomes. In addition to understanding the food system outcomes, this component maps the various elements of the food system: the activities (i.e. the value chain), the underlying drivers and the institutional and environmental context. The mapping includes an assessment of key indicators, as well as understanding (historical) trends, synergies and trade-offs of specific activities and indicators.

3. System behavior

Whereas system characteristics look at the status and trends for the various elements of the food system, system behaviour addresses the interactions between the elements. For example, the effects of climate change on food conservation practices, or the influence of cooling technology on local trade. Analysing system behaviour is crucial for understanding the food system and how systemic changes comes about; that is how a change in one part of the system affects the other parts. This component specifically looks into causal relationships between different elements of the food system. Understanding the causal relationships within the system is necessary to identify leverage points. These are places in the food system where targeted interventions can lead to system change and thus a change in the food system outcomes.

For each of the three components you will need different tools to explore the food system in order to find entry points for food loss and waste reduction interventions. The toolkit gives you a range of suggested tools, ranging from entry-level participatory tools to more resource-intensive analytical tools. Furthermore, guidance is provided on applying three Quality Principles:

1. System thinking
2. Stakeholder involvement
3. Equity & inclusiveness

An example

A Dutch embassy wishes to develop a new programme to address food loss in rural-urban food supply chains, with the aim to improve FNS and income generation in country X. Anecdotes of (post-harvest) food loss have triggered interest in this topic and the embassy tries to figure out which interventions could potentially have significant impact. Although the embassy staff has general knowledge of the agricultural sector in this country, there is a lack of insight into the rural-urban food supply chains and how these are influenced by dynamics in the broader food system. Therefore, the embassy wants to commission a food system analysis to get insight into potential intervention areas that could achieve multiple objectives (reduced food loss, youth employment, nutrition security, income generation).
Figure 2 shows which steps could be taken to design a food system analysis that is geared towards this question from a Dutch embassy. The bullets (small fonts) refer to specific tools described in the toolbox. Please note that this is only a suggestion, based on the context of this case. Other contexts and goals will require a different mix of tools from the 'cookbook' to complete the food system analysis.

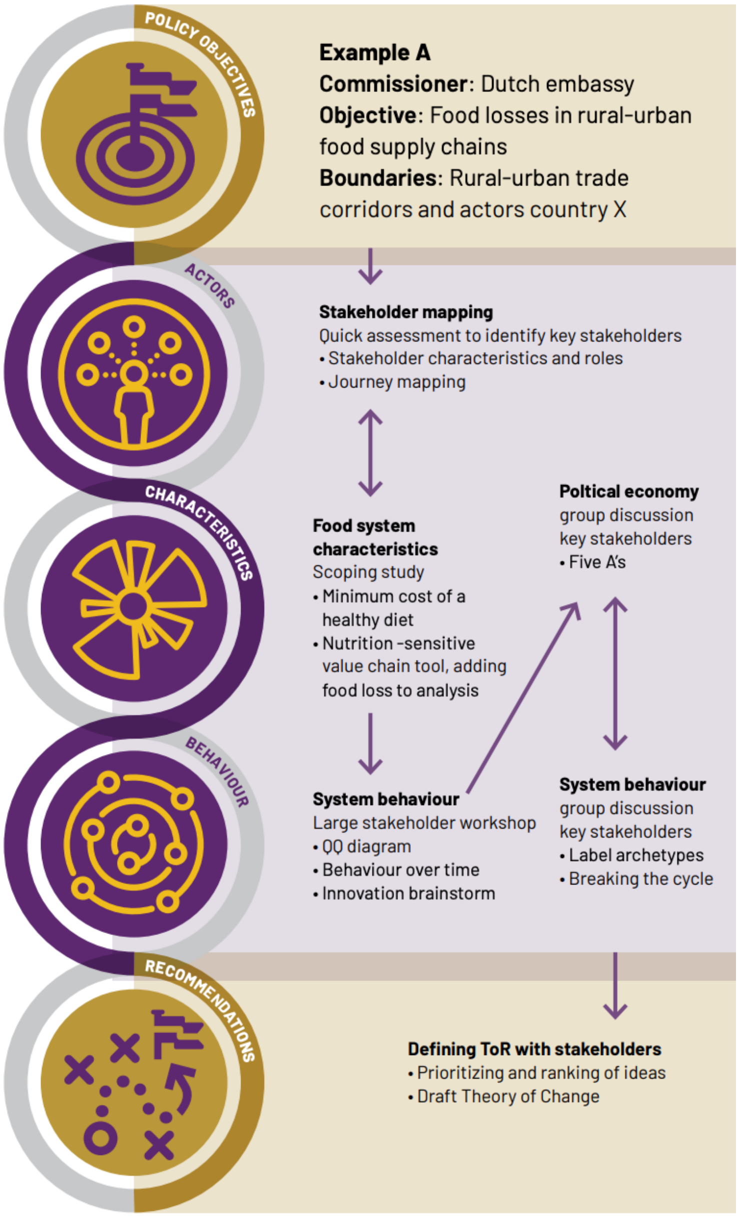

Figure 9. An example of a food system analysis process (Posthumus et al. 2021)

Deciding on entry points for intervention

After analysing the three dimensions of the food system (system actors, system characteristics, and system behaviour), choices can be made on where to intervene in the system.

Four pointers that can be of help:

1. **Identify pockets of resistance to change.** Are there powerful stakeholders or institutions that prevent change? How can these be addressed?
2. **Identify short-, medium- and long-term issues to address.** What are possibilities to react to urgent problems (quick wins)? What long-term challenges require a deeper transformation of the food system?
3. **Reconsider the portfolio of activities, interventions and policies.** Which portfolio components should be discontinued, improved, multiplied, or added?
4. **Be aware of 'lock-ins' at this stage.** Lock-ins are conditions that keep the system in its current state and inhibit system transformation. Examples are path dependencies or short-term thinking.

Putting a food system analysis into action

The food system analysis should result in a better understanding of the drivers and stakeholders influencing the entire food system. After the identification of leverage points for systemic change, choices will still need to be made as to which leverage points can be turned into actionable recommendations for strategies or interventions to reduce food loss and waste.
This final stage of the process explores the space for potential interventions directed at these leverage points. Inspired by the human-centred design approach, one can use the following three questions to focus one's recommendations: What do people desire? What is financially viable? What is technically and organisationally feasible? In the entire process, consult with stakeholders in order to validate your change logic.

Possible criteria for making these choices:

- Relevance, level of impact and sustainability of the systemic change for different social groups.
- Synergies and trade-offs of different choices for different social groups.
- Strengths, expertise and resources of the intervenir party, but also mandate and legitimacy to initiate change.
- Cost-effectiveness of interventions.
- The added value of the strategy in relation to existi initiatives, interventions or policies influencing the food system.
- Potential for creating synergies with other existing initiatives or partners.
- Balance between supporting and opposing forces (stakeholders) of your strategy, and your ability to influence these forces.
- Extent to which assumptions and risks underlying the strategy are reasonable, acceptable or manageable.

Conclusion

Finding the right entry points for FLW interventions is a difficult yet important task. It is important to design interventions that are effective to tackle the food loss and waste problem, but are also preventing potential further harm that could result from these interventions in other places of the food system. Identifying these entry points (or leverage points) requires doing a food system analysis. Getting a broader food system view on factors causing food losses and waste can help to zoom into the most relevant specific solutions to address FLW. How to do this in a participatory, context-sensitive, and efficient manner, is described in the Food System Decision Support Toolbox.

Suggested reading

Posthumus, H., J.M. Bosselaar, H. Brouwer. 2021. The food system decision support tool – a toolbox for food system analysis. Wageningen University & Research and KIT Royal Tropical Institute. **https://doi.org/10.18174/541410**

Herman Snel, Jan Broeze, Florine Kremer, Emily Osena, 2021. *A food system analysis of Kenya's mango, avocado and poultry sectors; Assessing opportunities to reduce food losses.* Wageningen Centre for Development Innovation, Wageningen University & Research. Report WCDI-21-185. Wageningen. **https://doi.org/10.18174/557094**

Chapter 06.

Adapting and adopting postharvest interventions to local supply chains

Michele Pedrotti and Jan Verschoor

Postharvest losses are a global problem but need local solutions. To develop effective interventions to reduce postharvest losses, it is necessary to adapt the intervention and its technology level to the specific local context, the specific food value chain, and the specific food product.

Figure 10. : The impact of postharvest intervention on the food system (Verschoor, Oostewechel, Koenderink, Pereira da Silva, & Hetterscheid, 2020)

Postharvest losses: a universal challenge and opportunity for countries?

FAO defined food loss as the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers (FAO, 2019). Food losses occurs mainly in the postharvest (PH) and processing stage. Postharvest loss (PHL) of food crops is defined as a loss of valuable food and of the inputs required to produce and distribute it along the food chain. The losses can be both in terms of quality and quantity. Quantity losses refer to losses that reduce the actual amount of food like weight loss or product discarding due to spoilage. Quality losses include nutritional losses or contamination of food. PHL may happen immediately after harvest, or during storage, transportation, processing, or distribution to consumers. The management of these processes is known as 'PH management'.

Globally in 2016, around 14% of food produced was lost from PH to distribution (FAO, 2019). This means that approximately 400 billion USD are lost every year in PHL – an astounding figure, corresponding to the GDP of Norway. While the magnitude estimations of PHL can vary greatly depending on the product, its supply chain, the areas and the economies involved, a common cause of PHL in low- and middle-income countries (LMIC) is inappropriate PH management. These deficient practices are often caused by a combination of lack of PH knowledge, poor market connections, inadequate technology and/or storage infrastructure.

An efficient PH management of food is essential for reaching the SDG Target 12.3 of halving the food loss along production and supply chains by 2030, but to reach other SDGs as well, including SDG 1 (No poverty) and SDG 2 (Zero hunger) (Figure 1). In this vein, in 2014, through the Malabo Declaration, the African Union established the PHL Management Strategy to halve by 2025 the PH losses of food crops including grains, fruits, vegetables, oil seeds and animal and fishery.

As recognised by different initiatives including the EAT LANCET planetary diet, the BCFN Double Health and Climate Pyramid and many national dietary guidelines, almost all countries globally need to improve the daily consumption of fresh vegetables and fruits. Investment in PH management for fruits and vegetables can be a very efficient strategy to improve food availability and access to these products, which are needed for a transition towards healthier and more sustainable diets. In general, the more perishable a product, the bigger the effect of PH interventions on food & nutrition security. Therefore, PH management and interventions can greatly contribute to improving food safety, food access and food availability in quantities and in time, which in turn can help improve dietary diversity. PH interventions can also improve the income of supply chain actors like producers by reducing food losses and waste (FLW) and, at the same time, reducing environmental pressure, since global food production is responsible for 21-37% of annual emissions (Rosenzweig et al., 2020).

Adapting the intervention to the local context is crucial for adoption

In terms of PH management, two strategies are mainly used: the first one concerns short-term cooling and logistical management to improve end-quality of the product on the market, reduce losses and increase the marketing distance. The second strategy focuses on medium- and long-term storage to be able to market the product over an extended period and reduce price fluctuations. While PHLs are a ubiquitous problem all around the world, there is not a unique single silver bullet solution that fits all products, supply chains and contexts. The approach depends on the product and market situation but in both cases significant gains can be achieved.

For example, cold chains – ensuring that products are stored at low temperatures during storage and transportation – are critical for reducing the quality and quantity losses of many different food products. However, cold chains are not always applicable or feasible. In many LMIC, cold chain infrastructures for fresh products have not yet been developed, since they require considerable investments in terms of resources and maintenance. Moreover, the opportunities to get a return on investment for commercial chain actors – the driving force in food value chains – are limited. The enabling environment – including governments and financial institutions - often fails to facilitate conditions that are needed for commercial chain actors to invest in PH interventions. And costs of interventions are not always directly benefitting chain actors where the intervention is performed, making adoption virtually impossible.

Different studies and interventions showed that, when the initial investment provided by external donors or subsidies from national institutions stops, the adoption rate of PH interventions drops dramatically. In the past, this has resulted in different cases of so-called 'white elephants': investments that seem promising on paper but cannot effectively be implemented often just end up impoverishing the recipient with the burden of maintenance and upkeep. Especially in the LMIC contexts, 'white elephants' can emerge when communities are not involved or taken into consideration in the intervention implementation; namely, when 'alien' technologies are imported into the community with limited compatibility with the local context. This often results in low or no adoption of these interventions, especially when external economic and knowledge support stops.

Therefore, when designing or evaluating a PH intervention it is important to consider not only the efficiency in reducing losses in both quantity and quality but also its adoption rate. The adoption rate of any given PH intervention can be influenced by many factors, including the following: its affordability, its acceptability by the society, its scalability, the availability of the required products and services, user awareness of intervention's benefits, technical feasibility, the adaptability to the environment and infrastructure, resource availability, the time it takes to impact and produce results, and the availability of extension services. Intervention uptake and sustainable usage is greatly enhanced when an intervention is developed and introduced through a participatory approach that involves local stakeholders in the decision-making process.

One of the major drivers for intervention adoption remains its profitability: while the enabling environment such as governments and financial institutions can facilitate conditions (improved access to markets, finance, and technology), a clear positive business case is needed for commercial value chain actors to increase adoption rates.

How to design an effective postharvest intervention

For putting in place an effective PH intervention with a high adoption rate, it is essential to carefully consider the context in which the operations will take place and in particular: the product and its market, the intervention type and level, the actors involved and the enablers.

Every *food product* has its own requirements and optimal conditions in PH management, including different handling procedures, storage conditions, and packaging. Perishable products like fruits, vegetables, meat, fish, and dairy products will have different requirements than grains, dried nuts, and flours. *Local production conditions* (climate, soil, (harvest)practices, etc.) are also important factors that influence how PH management can be optimised.

To facilitate the adoption of robust and efficient PH management strategies, a basic description of PH *Standard Operational Procedures* (SOPs) can be made for specific products, adapted to a local situation regarding quality demands, local availability of technology, logistics and markets (see references for some examples). These SOPs can be an excellent starting point to reduce losses with limited investments. SOPs applications can help to standardise products for specific markets and create awareness of the PH handling effects on quality in later stages of the value chain. They can also serve as a steppingstone for extension and introduction of new interventions for the gradual improvement of PH chains, while simultaneously reducing FLW.

PH interventions can be applied at *three different levels*: micro, meso and macro levels. The micro level looks at individual links in a particular food supply chain, like an intervention that aims at improving the handling of the food product on the farm to reduce food loss. A meso level intervention considers the relation between different actors of the supply chain, so no longer a one-on-one relation but larger groups and different stakeholders. For example, the training and education of farmers groups by local extension officers on postharvest practices can be considered a meso-level intervention. Finally, macro level interventions focus on FLW as a more systematic issue to enable investments and the adoption of good practices. Interventions to extend the network of paved roads, tax-reduction measures for certain technologies, or the facilitation of extension services with content, material and finance are all examples of macro level interventions which involve governmental bodies, affecting the entire supply chain and/or an entire group of actors. This structure facilitates the logical mapping of causes, solutions, and actors that should be involved, and recognises the cascade effects where dynamics at one level can also affect other levels.

- **Technology** – Physical tools or equipment;
- **Finance & investment** – Funding, credit, insurance and other financial products and services;
- **Best Practices** – Changing processes or practices based on knowledge of how to reduce FLW;
- **Organization** – Coordination inside food chains;
- **Policy** – Government policy affecting the incentive structure and enabling environment;
- **Economics** – Markets and market linkages, economic decision-making.

Many solutions to reduce PHL relate to technological interventions such as cold storage or processing technologies since they can give an immediate benefit. When putting in place such intervention in LMIC, it is important to consider that most of the producers are smallholder farmers and the midstream value chain operations – where most of the PHL occur - are dominated by small, informal businesses. The investment capacity of these actors is typically low and most of them lack access to financing. Moreover, in LMIC, the majority of consumers spend more than 50% of their household budget on food and they are not willing or able to pay a premium price for improved quality. Therefore, the limited additional price that can be obtained in the market for a better-quality product does not justify large investments in postharvest. In this case, rather than choosing high-level technology investments, it is better to go for more feasible low or mid-technology interventions that are cheaper and easier to implement.

Enabling environment

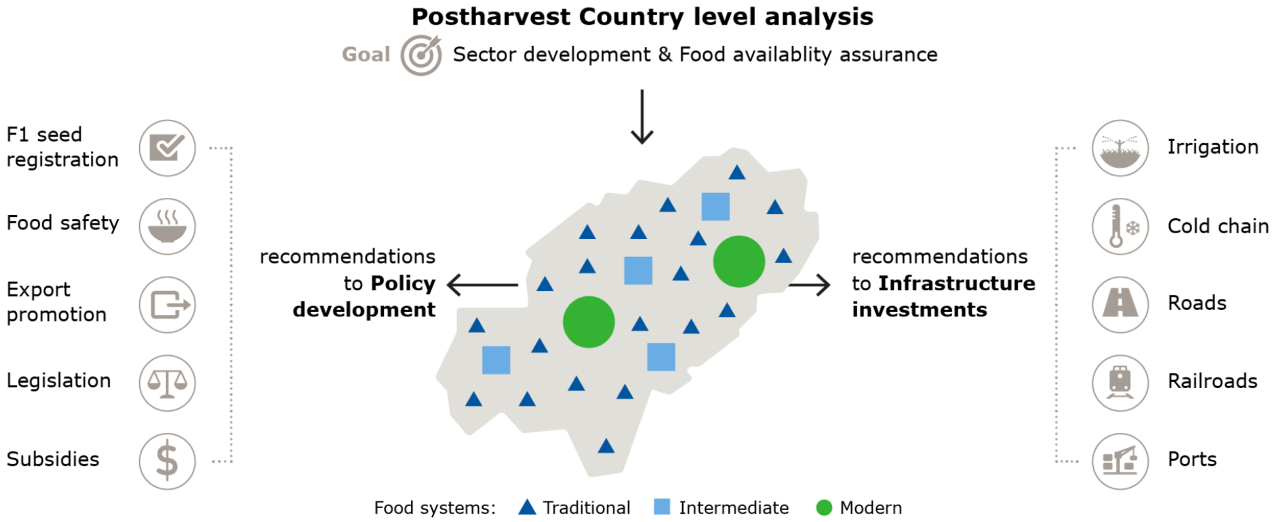

Figure 11. Visualisation on country level of the enabling environment for developing postharvest interventions and management with a focus on government policy development and investment strategy (Verschoor et al., 2020)

Based on the type and level of interventions, different actors could be involved. Among the main actors directly involved in PHL reduction operations are the producers, the traders, the wholesalers, and the retailers. It is also important to consider that, especially in LMIC, many of these actors operate in the informal sector, which implies that different actions are needed for involving them. For tapping the potential of these reduction actions, other enablers should be involved: educators and extension services can help in sharing knowledge and best practices, policy makers can improve infrastructures, communications and providing financial resources through subsidies or tax measures. Different enablers can also help with the design and adoption of a PH intervention. Among the most important are education (e.g. by implementation of SOPs or by knowledge exchange) and the facilitation of infrastructure (e.g. roads, railroads, harbour, water etc.).

In light of these considerations, it becomes even clearer that specific strategies and technological solutions should be adopted depending on the product and on the context to design a successful PH intervention. To facilitate this process, PH assessment tools can be used for assessing the maturity of the PH management in the considered context. This can lead to a better understanding of the aforementioned factors that can greatly affect the efficiency and the adoption rate of the interventions (Figure 11).

Tips and tricks for adapting and adopting PH interventions

PH management is a powerful tool for FLW reduction, which at the same time can help in improving fresh products' availability and reducing pressure on natural resources used for food production, transportation, transformation, and distribution. Stakeholders and policy makers interested in implementing PH interventions or improving PH management should start with basic steps like developing and introducing PH SOPs tailored to the local context. Use of SOPs can boost quality awareness, standardisation, market alignment and options for extension and gradual technology uptake. Moreover, when designing a PH intervention, it is fundamental to consider the local context, including the PH management maturity, the actors involved, the intervention level and the possible enablers. A participatory approach, together with the inclusion of positive business cases for commercial chain actors involved could help in increasing the adoption rate. Targeted policies can act as potent enablers for improving PH interventions at the macro level. For example, policies could improve infrastructure like roads to facilitate logistics and transportation – or power and water availability for primary production, storage, and food transformation – while also stimulating subsidies for PH investments. While technology interventions can greatly contribute to the reduction of PHL, it is important to adjust the technology level to the application scenario, which includes available knowledge and resources and profitability. However, pushing only for these kind of interventions in LMIC is likely to lead to low adoption rates or, even worse, to white elephants. Instead of using a single approach to transform the food system, a portfolio of policies, technologies, education, and incentives must be tailored to each food system's enabling and constraining factors.

Suggested reading

FAO (2019). *The State of Food and Agriculture. Moving Forward on Food Loss and Wast Reduction Food and Agriculture.*

Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Portugal-Pereira, J. (2020). Climate change responses benefit from a global food system approach. *Nature Food*, 1(2), 94-97. doi:10.1038/s43016-020-0031-z

Soethoudt, J. M., Pedrotti, M., Bos-Brouwer, H. E. J., & Castelein, R. B. (2021). *Adoption of food loss and waste-reducing interventions in Low- and Middle-Income Countries.*

Verschoor, J. A., Oostewechel, R. J. A., Koenderink, N. J. J. P., Pereira da Silva, F., & Hetterscheid, S. (2020). *Postharvest interventions key for improvement of food systems: Exploring the impact of postharvest interventions on increasing food availability, stability and income generation in developing economies.*

Examples of WFBR projects in which Standard Operational Procudures (SOPs) were developed:

- 6239 2090 Benin Export Competitive Reinforcement. (Development of SOPs for the conservation of fresh/perishable agricultural produce including export products, *Mango, tropical leafy vegetables, Papaya solo, pineapple, Green pepper*)
- 6239 1982 Jordan Export Competitiveness (*Tomato, strawberry, bell pepper*)
- 6239 1926 Logistics Service Centre Haiti (*Mango, avocado, pineapple*)

Chapter 07.

Principles of circular valorisation of agri-food residues and wastes

Jan Broeze and Wolter Elbersen

Common waste hierarchies propose fixed priorities for food surplus and waste valorisation (like 'extraction of food components is more circular than applying as animal feed' or 'applying as animal feed is more circular than applying as energy application'). However, all biomass is made up of very different components such a fiber, protein, starch and often scarce nutrients. The best application depends on the composition of the material. An application that is suitable for one biomass type may be less appropriate for another. Therefore, we propose a dedicated framework that prioritises potential applications based on composition, and efficiency of use and re-use potential. We should also consider that the most circular application may not be the best solution if the market does not exist or if other environmental issues occur.

Circularity is a way towards sustain-ability, though not a goal in itself.

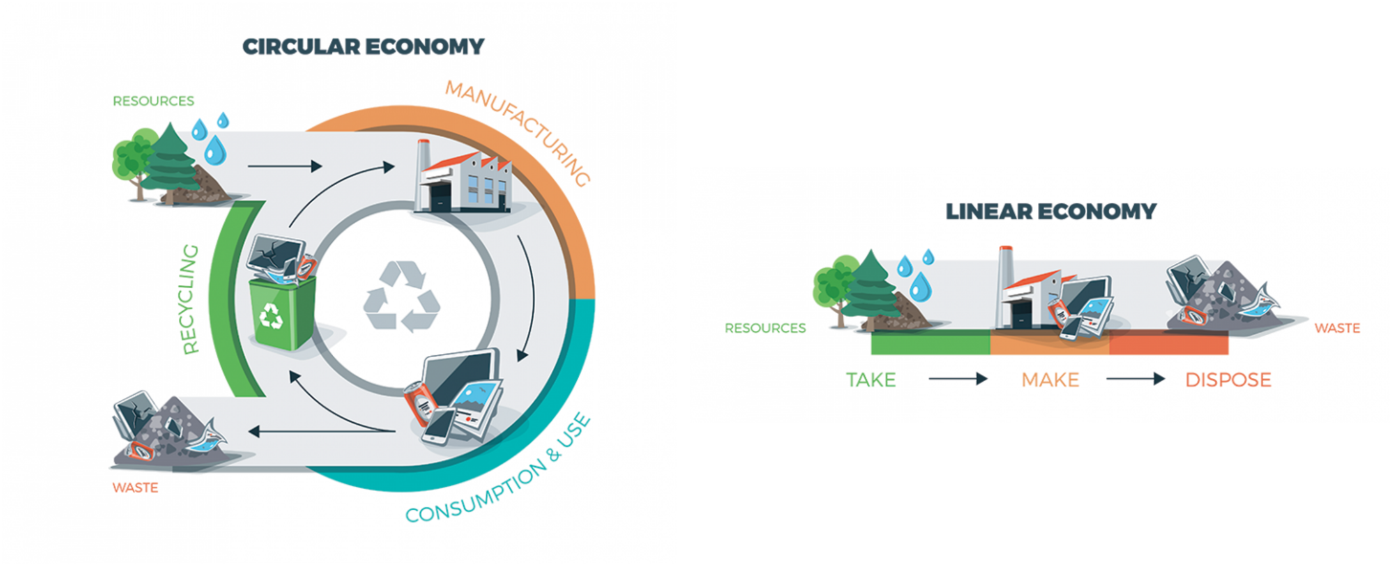

Figure 12. Illustration of the linear economy vs the circular economy in which resources are re-used and waste is minimised (De Haas, 2019).

In the production and supply of food, inevitably significant volumes of residues (like straw and food processing residues), losses and waste are generated. With the new momentum for circularity that is on the rise, we are increasingly often getting the question how to best valorise these streams. Although almost any valorisation option for residues may be considered circular, one application is more circular than another. What does this entail?

Circular use of residues and waste is a measure to reach broader sustainability goals. Many environmental problems can be traced back to a wasteful handling of raw materials (PBL, 2021). In a circular economy, chains are designed in such a way that waste and pollution no longer exist; products and materials are preserved in the system and natural systems are regenerated (after the Ellen MacArthur foundation). The aim is therefore to keep materials in use as long as possible, which means to (re) use items as much as possible, so that the consumer need is met with minimal replacement. The need for regenerating natural systems means that at the same time, biodiversity has to be protected and the production capacity of soils has to be maintained or improved.

Choosing the most circular option results in the most valuable use (and re-use) options and minimises the need for virgin material/crops. In that sense, circularity is a way towards sustainability, not a goal in itself, just as food loss and waste prevention is not a goal in itself but a means to an end. For biomass this means:

- In food chains, maximise the functional use to minimise inefficiencies.
- In biobased applications, maintain functionality of the biomass components as much as possible, so that the product after use can be of maximum use in subsequent applications.
- Postpone the final use, i.e., energy production or application as a fertiliser.

These principles induce maximum utilisation efficiency and potential of re-use; we call that *sequential cascading*.

Besides that, the functional value of a biomass may be increased by fractionation and maximising the functional use per fraction. This not only applies to technical processing; even livestock farming results in multiple products. Dairy cattle, for example, can deliver amongst others milk, meat products and manure, a valuable fertiliser. The total circular value can be enhanced through biogas production from the manure, which preserves the recalcitrant organic matter and nutrients in the manure and additionally induces a sustainable co-production of energy (methane). We call the principle of maximising value per fraction parallel optimisation.

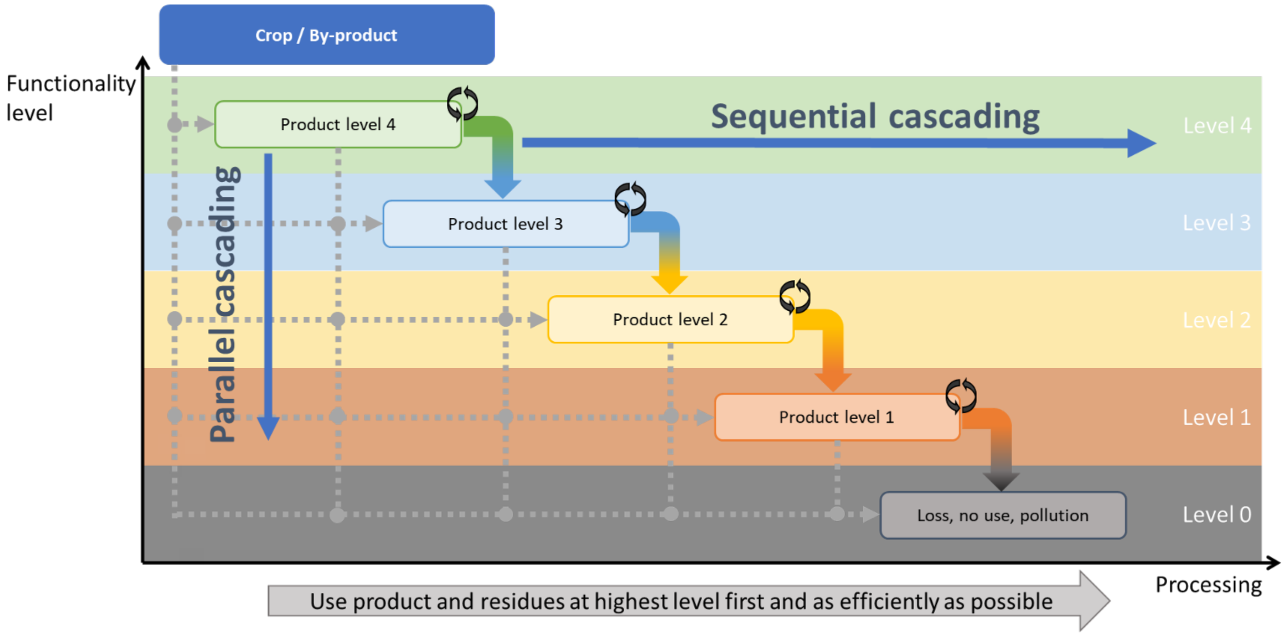

Figure 13. Illustration of sequential and parallel cascading of a biomass crop or by-product. The levels indicate the functionality that remains when it is used. Based on Spiker et al, (2020) and Höglmeier et al., (2015)

In order to foster circular development, insight is needed into which (novel) applications of biomass actually contribute to circularity. Such insight contributes to identifying and prioritising opportunities for improvement and to assessing ideas for new utilization options. Practical questions that arise include: Which residues are available? What is the current application? Which streams are not being used, and why not? How circular is the use now? Are alternative applications of the biomass more circular than the current applications?

Biomass is considered circular in itself: plants capture CO_2 that, when the biomass is used, is eventually converted to CO_2 again when it breaks down or is burned. This cycle can go on indefinitely, however, the production requires land, water, labor, energy and last but not least, fertilisers/nutrients including phosphate and potassium: raw materials whose readily available concentrated supplies are limited. As they are used in agriculture they are diluted in the ecosystem. Nitrogen fertilisation is needed which, just like CO_2, is renewable from the air; the source is not exhausted, but the production (capture) requires a lot of energy and the production and use induces greenhouse gas emissions in the form of CO_2 and N_2O (nitrous oxide) and pollution as NOx emissions. Land and water required for biomass production are scarce resources, especially in view of deforestation issues. Moreover, processing and transportation require energy and fuels. That is why circular use of biomass is important: Less virgin materials are needed.

This is illustrated by an example in which environmental impacts of conventional use of wood and residual streams derived from wood are compared to a system in which cascading is improved (Höglmeier et al., 2015). Cascading in this example (Figure 14) leads to a 14% reduction in the total need for virgin wood and to a 7% reduction of total greenhouse gas emissions. Postponing final uses of wood and replacing products with high greenhouse gas intensities with wood products will increase GHG and biomass saving.

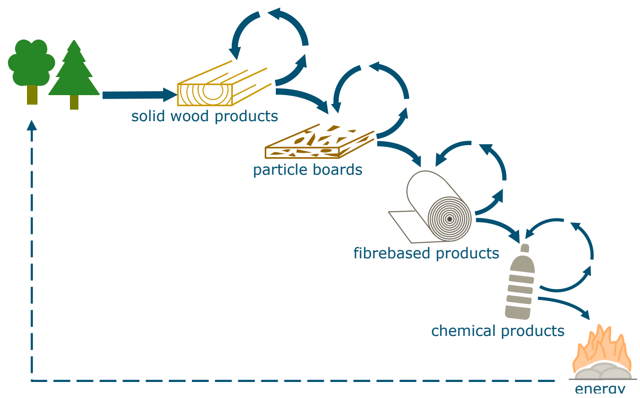

Figure 14. Maximising cascading of wood and derived products (after Höglmeier et al., 2015).

Prioritising biomass application for maximising circularity is a complex challenge

In a (circular) agro-food system, biomass is expected to fulfil a large variety of functions, like food for nutrition, feed for producing food, material uses (wood products, paper) and energy, fuels, and last but not least, contributing to soil quality maintenance (nutrients and carbon). As in the wood example given above, applying a biomass stream at the highest possible function maximises the total potential use, provided that the application is efficient.

It is important to understand that the cascading hierarchy does not indicate or is the same as the importance or value of biomass applications. Final uses of biomass such as energy and application to the soil are final uses which are valuable and important. If an animal eats a residue, it will also generate large amounts of manure, which can be used to conserve soil quality. Most nutrients will be conserved. Similarly, using wood for products will still make it possible to make energy after it is discarded and has had many uses. Making biogas from a residue will probably not reduce its value as a soil amendment, probably in the contrary.

Generic priorities for valorising food surplus and waste are formulated in various frameworks, for example, the biomass value pyramid, Moerman's ladder and the food waste hierarchy (e.g. Figure 4). These frameworks have strongly stimulated the thinking and development of more circular valorisation practices of former waste streams. However, these dedicated frameworks pose rigid priorities (e.g. 'land application is more preferable than combustion for energy generation'); this ignores the fact that biomaterial generally consists of several components, of which each may have a different value and efficiency in an application. For example, starch has very little value when applied to the soil, but can be converted into biofuel very efficiently; applying a stream with significant content of starch and poorly digestible fibres in feed or biogas fermentation will keep the persistent fibre fraction largely available for the soil.

What is the most circular application cannot be easily answered based on the generic priorities of the waste hierarchies. What is most preferrable depends on the perspective, often leading to competing claims and conflicting interests. The discussion (and decision makers) needs objectification. A framework is needed that reflects the efficiency to generate a new consumer product, and (for biobased applications) to what rate that product can be recycled again. We propose a framework that addresses both efficiency and functionality:

1. **Efficiency:** The use of biomass often results in an end product with limited efficiency. For example, when reusing wood, part of the material is degraded to sawdust and cut-offs (possible uses ranges from chipboard to energy). Likewise, for animal feed applications, the conversion rate from feed to food product (meat, egg, milk) is less than one. The efficiency can vary amongst components and between specific applications.

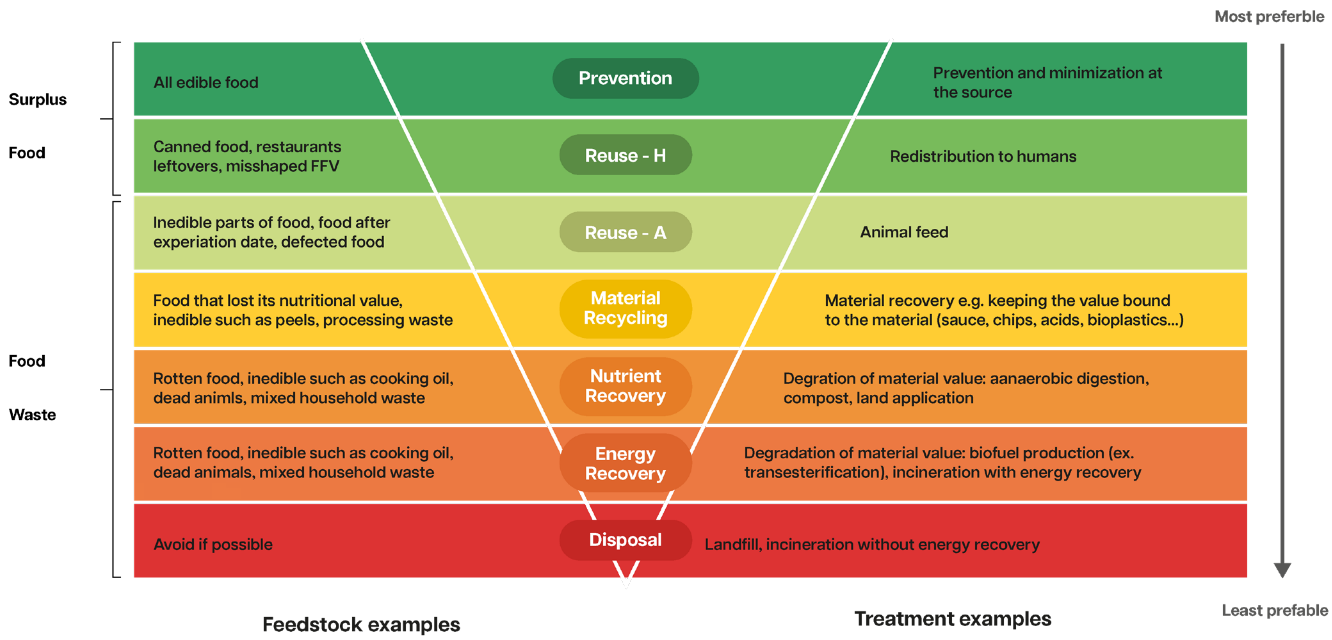

Figure 15. Updated hierarchy for food surplus and waste (Teigiserova et al., 2020).

2. **Functionality:**
   This points at the (reuse) value of the product. Food and unprocessed materials (such as wood) are assigned the highest functionality value (see also Figure 12).

   For biobased application, we distinguish the following levels in order of increasing functionality value:
   1. lost, untapped
   2. carbon lost, converted into energy,
   3. molecules converted into functional molecules (such as bioplastics), possibly broken down into small organic molecules, such as sugars, starch, or ethanol,
   4. macrostructure broken down, molecular structure retained (as in paper and fiber board),
   5. maintain macro structure (think of wood products).

Soil application (where especially nutrients and persistent organic matter essential for soil health) is again different from food or biobased application; it has characteristics of 'molecular structure retained' as well as 'carbon lost' (because the material cannot be recovered).

The efficiency and functionality value must be determined per component (fibre, protein (N), carbohydrate (sugar, starch), oils and fats, and nutrients (P, K, etc.)) in the biomass.

The degree of circularity of a component in an application is the product of efficiency and functionality; the total value of the biomass application is the sum of values per component, divided by the value it had in the original function. For processes in which multiple products are generated (animal feed is converted to food and manure; likewise, biorefinery processes result in multiple products), the total circularity result is the sum of circularity result per product. For example, when applying a protein-rich stream in animal feed, the protein is converted to food protein with an efficiency between 10 and 25% (exact value depends on animal type and farm management) and especially persistent fibers and significant part of the minerals are converted into manure/fertiliser. Crop residues with low protein content and significant mineral content may have low nutritional value. For such streams application in animal feed has little circularity benefit compared to direct application to the soil.

Building blocks of an assessment framework for biomass circularity

In order to quantify the contribution of a biomaterial in an application towards a consumer product, and to compare the degree of circularity of different applications, data on biomass compositions, conversion *efficiencies* and *functionalities* are needed.

Whereas *compositional* data of primary crop products and food products are abundantly available (for instance, the USDA Food Database), agricultural and processing residues as well as food waste flows are less studied, and are less homogeneous streams. For streams that are commercially exploited for animal feed, animal nutrition data and some nutrient compositions are gathered at feedipedia.org. Streams with biobased potentials are increasingly addressed in research projects. Compositional data of tertiary residues (including food waste streams) are very scarce.

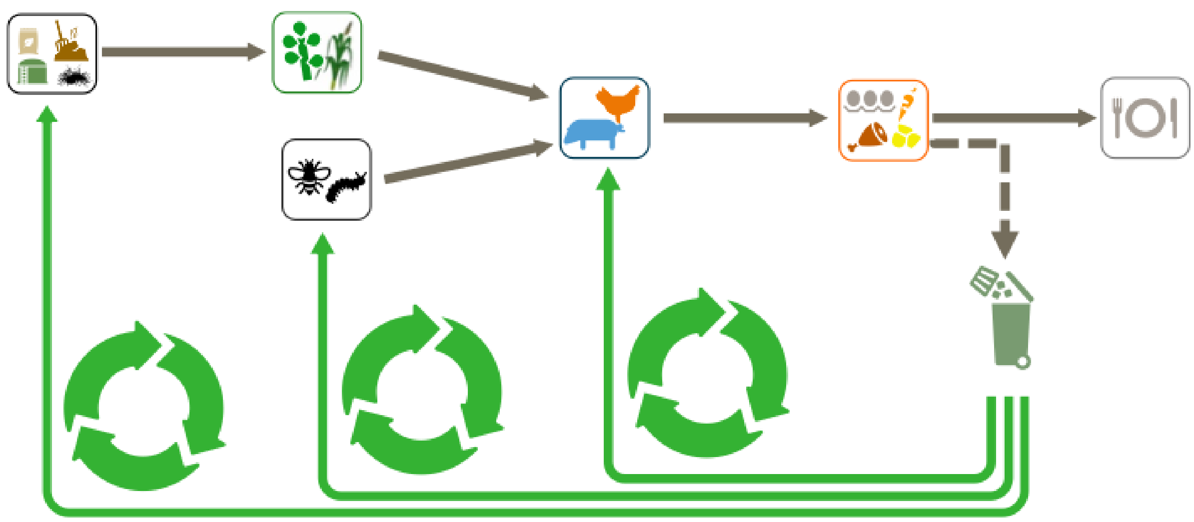

Figure 16. Different circular options are available for the utilisation of food waste streams, like direct use for feed, via insects as feed or via composting (some of these pathways are only admitted for selected streams). Especially food waste streams with a high content of proteins, simple carbohydrates and fats are more functional in feed than for composting; consequently, the circularity of use in feed is higher than via composting.

Furthermore, conversion *efficiencies* must be identified for a large set of applications, varying from different types of livestock, extraction of food ingredients from residues, biobased applications including conversion to biochemicals and energy application and conversion processes to fertilisers. Deriving conversion of feed nutritional data to food generation ratios requires amongst others estimates of the edible fraction of slaughtered livestock and other inefficiencies along the production chain. Progress on biobased production processes must be represented by conversion efficiencies parameters.

As explained above, assessing functionality is quite challenging. Whereas for the food and biomaterials domain notions crystallise, adequate representation of the functional value of soil carbon and other biobased applications is still challenging.

Benefits of circularity

Through adopting circular uses of biomass (residues) streams the total value generation is maximized. In other words, the total biomass required to fulfil all global demands is minimised, resulting in a relatively low land-use footprint and climate impact of production. Better quantitative insight in tradeoffs is necessary to come to effective, no-regret sustainable developments. In the meantime, ideas for more circular use of residues should be pursued.

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Chapter 08.

Food safety control is key to reducing food losses and waste

Ine van der Fels-Klerx

The prevention and control of fungal infection and related mycotoxin contamination - as well as other food safety hazards in food crops - is not only key to reducing food loss and waste, but also increases food security. FLW in LMIC mainly occur in food business operators in midstream value chain stages, which mainly include small, informal businesses. Food safety management practices are not yet common among these midstream business operators in LMIC. Easy to handle tools for farmers and other small business operators to help them with food safety management, in particular to prevent and control mycotoxins, can help to reduce the rates at which their crops are affected, and thus reduce FLW.

1. Food safety and related disease burden

Food safety is defined (Codex Alimentarius, 2003) as the situation in which food is produced, handled, prepared and stored in such a way that consumer health is not affected upon consumption of the food, neither in the short nor the long run. Food can be contaminated with food safety hazards, or have a certain condition, that may cause health effects after consumption of the particular food item. Such food safety hazards are agents in or on the food, or a condition of the food, that could cause adverse effects to health; they are chemical, microbiological or physical in nature (ISO 2016). The presence of safety hazards in foods can lead to severe impacts on animal and human health, as well as on production and trade.

In a large study, FAO estimated the global burden of disease related to four main food safety hazards: aflatoxin B1, cyanide, dioxins and peanut allergy. Disease burden was expressed in Disability Adjusted Life Years (DALYs), taking into account both mortality and morbidity due to diseases in the population. DALYs (with 95% confidence interval) were estimated to be 636,869 (267,142-1,617,081) globally. Of the four considered chemicals, Aflatoxin B1 had the greatest impact on deaths and on DALYs. The impact in terms of DALYs was greatest on the African continent and in South-East Asia, being nearly 20 foodborne DALY per 100.000 inhabitants in each of the two regions. In Africa, DALYs were mainly caused by Aflatoxin B1.

Aflatoxins are secondary metabolites of the fungi *Aspergillus flavus*, *Aspergillus parasiticus* and, though less frequently, other Aspergillus species such as A. *nomius*. These species are very prevalent in food crops, particularly maize, peanuts (groundnuts), oilseeds, and tree nuts in tropical and subtropical regions worldwide. The aflatoxins these species can produce consist of a group of four aflatoxins, including Aflatoxin B1, B2, B1 and G2. Of the four aflatoxins produced by these fungi, aflatoxin B1 occurs most frequently in human food crops, such as maize and nuts (ground nuts and treenuts). Aflatoxins are very toxic chemical compounds with severe effects on human health. They can result in immune system suppression, cancer, liver cirrhosis, and stunting. The International Agency for Research on Cancer (IARC, 2018) has classified aflatoxins as group 1 - carcinogenic to humans.

Human exposure to aflatoxins mainly occurs via food intake. A recent systematic review on the aflatoxin situation in Africa concluded that concentrations of aflatoxins in staple foods in Africa can occasionally reach very high levels, causing acute aflatoxicosis. Overall human exposure is also high through contamination of staple crops, leading to a substantial increase in long-term disease burden (Meijer et al., 2021).

2. Food safety management, quality management and HACCP

Ensuring the safety of food products is of utmost importance, and is part of food quality management, since food safety can be considered a specific aspect of food quality (Luning and Marcelis, 2009). Quality management refers to all activities that food business organisations (FBO) use to direct, control, and co-ordinate quality; it includes formulating a quality policy and setting quality objectives, as well as quality planning, control, assurance, and improvement (Luning et al., 2002). The same aspects are relevant to food safety management.

In Europe, with the General Food Law (GFL) coming into force in 2002, each FBO is responsible for food safety of its own products, at its own enterprise. Also, the GFL has made it compulsory for every FBO to have a Hazard Analysis Critical Control Point (HACCP) system, a food safety management system. In Africa, on the contrary, very few companies, except large and exporting companies, have implemented HACCP (Kussaga et al., 2014). HACCP aims to ensure the food produced complies with predefined safety targets (e.g. legal limits) within set tolerances. Checks are done regularly to verify that the product complies with the set boundaries. As part of HACCP, a hazard evaluation is done, that is, critical control points are established in the food production for the identification of hazards that may have been introduced. Then, it is evaluated if the hazards can form a risk to human health. While FBOs perform sampling and analyses of food safety hazards as part of HACCP (i.e. verification and validation steps) governments also perform food safety checks. When the aim is to detect food safety contaminations, such food safety monitoring should be risk based, entailing that sampling should focus on those products, regions, etc. that have the highest probability of being contaminated. Also, analyses should focus on those hazards with the highest likelihood of being present in the collected sample. Risk-based monitoring will increase the chance of detecting food contaminations.

In designing risk-based monitoring programmes, it is necessary to estimate which food products have the highest likelihood of being contaminated and which hazards are most likely to be present. To this end, historical data/observations can be used as well as prediction models and trend analyses, among others. One of the food safety priorities in LIMC is prevention and control of aflatoxins, and predictive models for these and other mycotoxins could be helpful in this respect.

3. Mycotoxin predictions

Mycotoxins are chemical compounds formed by fungi, upon and after infection of crops. As mentioned above, these include aflatoxins produced by *Aspergillus spp.*, but also entail others, such as mycotoxins produced by Fusarium *spp*. Fungal infection and mycotoxin formation are influenced by environmental factors and by management practices. In the field, where agricultural crops like wheat and maize are grown, fungal infection of the crop is mainly affected by weather during critical periods of crop cultivation, in particular crop flowering and maturation. Additionally, farm management factors like crop type planted and soil type play a role as well. Farming practices to mitigate aflatoxins that have been tested under African conditions include the use of resistant crop varieties, and other agronomic practices such as planting and harvest date, crop rotation, pest control, irrigation, and – lately – also the addition to the soil of non-toxins producing fungi that compete with the mycotoxin-producing species (Meijer et al., 2021).

The use of pre-harvest predictive models for mycotoxins could be helpful for farmers; such models give predictions - already during the season - of mycotoxin presence at harvest. To date, predictive models for aflatoxins have been developed in other areas of the world, such as South and Eastern Europe, the US and Australia (Battiliani et al., 2013; Battilani et al., 2016; Van der Fels-Klerx et al., Chauchan et al., 2018). However, to date, predictive models have minimally been developed and applied in Africa, even though highly needed, given the relative high aflatoxin contamination. Model development can be based on historical data related to aflatoxin concentrations in the harvested crop, using an empirical, mechanistic and/or machine learning approach. The major hurdle for predictive model development is the necessity of these historical aflatoxin contamination data at or shortly after harvest. These data are hardly available to date in the amounts needed for the development of predictive models with satisfactory performance. If such models were available for aflatoxins in staple crops such as maize and nuts, they could help African farmers by providing specific agricultural advice during the most critical points in the phenological cycle: preseason insight including sowing timing and the use of crop varieties, and preharvest advice about management and harvest timing. Also, predictive models could help to decide on risk-based testing of certain areas; the focus of monitoring could be on those areas with high predicted aflatoxin contamination.
So, for preharvest predictive model development, it is recommended to collect field data related to aflatoxins at harvest.

Predictive aflatoxin models can be integrated into decision support systems and/or apps to focus on the optimisation of value for smallholders by minimising yield and nutritional losses, which can propagate value throughout the production and postharvest phases.

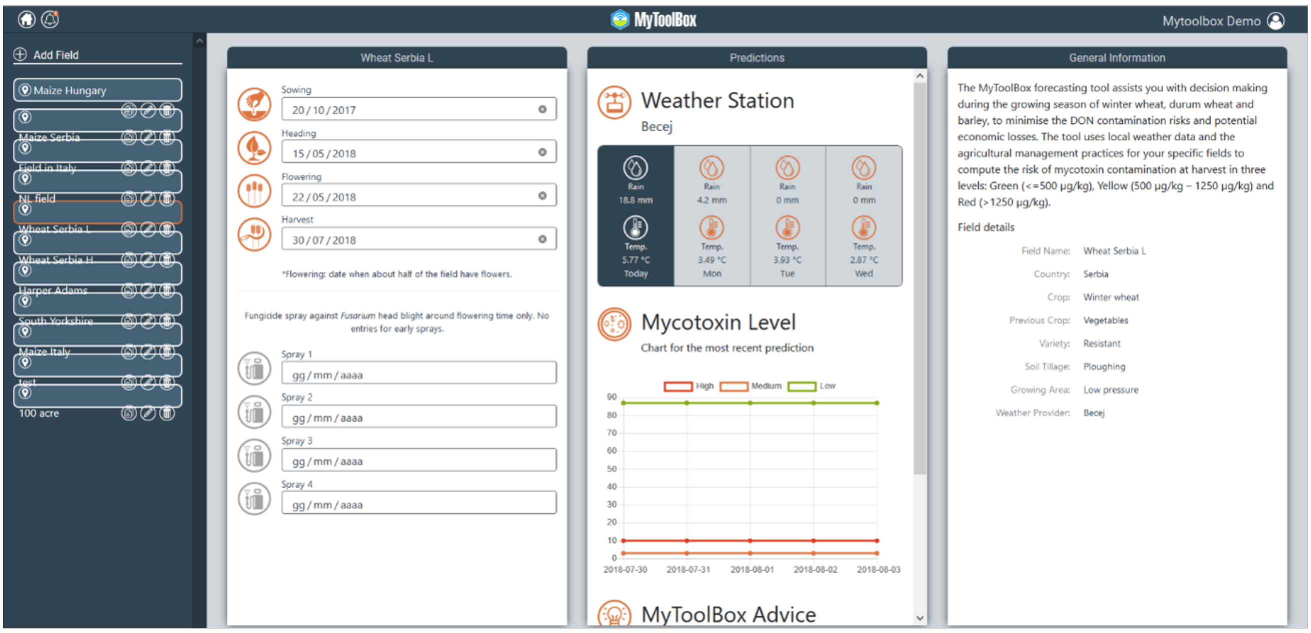

Figure 17. DSS pre-harvest forecasting tool: Display forecasts for deoxynivalenol in wheat, durum wheat and barley

In the course of the European project MyToolbox, such a decision support system has been developed for several European feed and food supply chains, as based on wheat, barley, maize and nuts (Van der Fels-Klerx et al., 2022). The platform includes an informative module with guidelines and information for users on how to prevent and control mycotoxins in the different stages of the chain. Also, it includes an interactive module, which provides early predictions of mycotoxins in grains, using inserted user information for the specific field (Figure 1). Once predictive models for aflatoxins in maize in LIMC have been developed, such a decision support tool can also be made to help farmers and other supply chain actors to prevent and control this major mycotoxin in feed and food crops, and thereby reduce food losses and increase food security.

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Chapter 09.

Long versus short food supply chains and implications for food losses and waste

Bob Castelein

Short Food Supply Chains (SFSCs) are recommended as a pathway to reduce food loss and waste (FLW). However, there is still ambiguity about what exactly constitutes a SFSC, and what features these should have to effectively reduce FLW. Moreover, the workings and potential relevance of SFSCs differ considerably across food systems, geographies, and economies. This chapter discusses when and where shortening supply chains makes sense to address FLW.

Short Food Supply Chains (SFSC for short) are hypothesised to be a more sustainable, resilient and equitable alternative to long, industrialised, often international food supply chains dominated by large corporate actors. SFSCs are recommended as one of the pathways to reduce loss and waste: the often-quoted 2011 FAO publication by Gustavsson et al. (*Global Food Losses and Food Waste*) mentions shortening supply chains as a key preventive measure to address FLW, in part because when farmers sell their products closer to the consumer, more food reaches the consumer, as intermediaries with stringent product quality standards (also related to cosmetic criteria unrelated to safety or healthiness) such as supermarkets are omitted. A more recent flagship report by FAO (*The State of Food Security and Nutrition in the World, 2020*) recommends shortening food supply chains for another reason: urban and peri-urban agriculture creates proximity to major consumer markets in cities, while preventing losses in longer supply chains plagued by weak market linkages and poor infrastructure.

What is 'short' about short food supply chains?

These two recommendations reflect several aspects we need to clarify regarding short food supply chains, their advantages and disadvantages relative to 'long' food supply chains, and the contexts in which these become relevant. Most importantly, SFSCs are considered 'shorter' in terms of smaller distances the food travels between producer and consumer, as well as in terms of the smaller number of intermediaries between the farmer and the consumer. In practice, the term will be used for a variety of constellations that differ on one or both of these aspects from 'long' food supply chains that span large distances and/or have a large number of intermediaries between farmer and consumer. Three broad types of SFSCs can be distinguished: Firstly, *face-to-face SFSCs*, in which consumers procure their food directly from the farmer (through farm shops, markets, roadside sales, delivery etc.), in which there are no intermediaries. Secondly, *proximate SFSCs* connect farmers to consumers through a limited number of intermediaries, such as farm group shops, cooperatives, markets, local outlets, or dedicated retailers. A third (outlier) category of short food supply chains - *extended SFSCs* - can span larger distances but the local origin of food is still highlighted (through for example labels and certification) and a source of value to consumers.

The first two of these types can both be subsumed under the term *local food systems* as well – food systems in which production and consumption are located in close geographical (short distances) and relational (limited number of supply chain links between producer and consumer) proximity. Relational proximity is also indicative of the type of intermediaries and their relations with producers and consumers: long food supply chains are often dominated by a small number of large multinational corporations (e.g. traders, supermarket chains) that exert their market power on smaller producers and offer consumers products with standardized characteristics of which the specific origin is of minor importance. Intermediaries in local food systems and SFSCs, on the other hand, have limited market power, are often controlled by producers and consumers themselves, and so leave producers and consumers to be the most powerful actors in the food system.

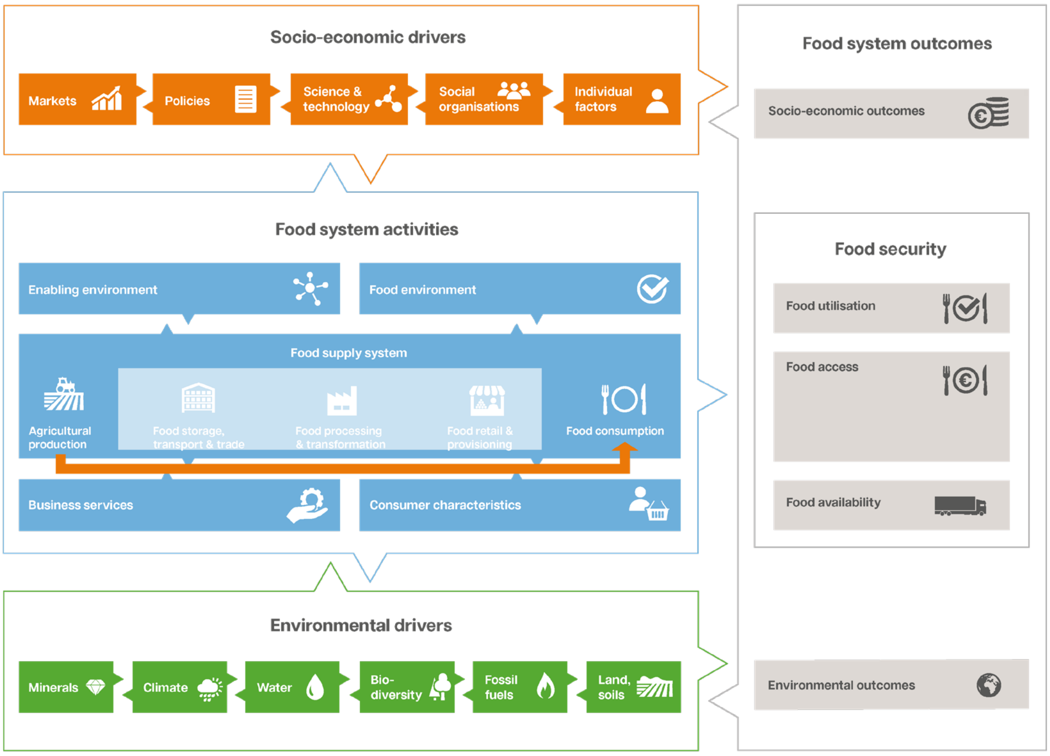

Figure 18 Shortening food supply chains within the food system (author's adaptation, based on Van Berkum et al. (2018)

Greater proximity, less loss and waste?

Regarding FLW specifically, SFSCs are hypothesised to reduce FLW through four broadly defined mechanisms. The first is straightforward, namely that geographical shortening of the food supply chain reduces the distance and time between production and consumption, resulting in a fresher product arriving in the consumer household, with less time to spoil and longer remaining shelf life. Second, when there are fewer intermediaries in the chain between farmers and consumers, information exchange (including price signals) from one end of the chain to the other is more effective. Through this economic mechanism, demand and supply can be better aligned and less food ends up lost or wasted due to mismatches. Third, having fewer intermediaries in the chain reduces losses and waste due to practices of these intermediaries – who are often not primarily driven by incentives to reduce FLW. For example, large retail chains have quality standards regarding product size, weight, and appearance, leading off-spec products to be discarded along the chain, even if they are still safe and healthy to consume. Moreover, through their supply agreements they incentivise overproduction, and marketing practices incentivise overconsumption by consumers. Limiting these practices in food supply chains would also effectively reduce losses and waste. Fourth, it is presumed that shorter food supply chains and greater proximity between producers and consumers change consumers' attitudes towards the food itself. Knowing where, by whom and how their food is produced stimulates people to be more conscious about the food and more aware of the food system they are a part of, and to exhibit less wasteful behaviour. It should be noted that – despite the intuitive appeal of shorter food supply chains – empirical research on the effect of shortening food supply chains on FLW is very limited, and when available, often ambiguous. More broadly than only their relation to food losses and waste, SFSCs are becoming more widely accepted in policy circles as a mechanism to achieve a variety of food system outcomes. They are assumed to be more inclusive, due to smaller producers receiving a fair price for their products; more resilient, as they are less affected by disruptions in international trade (a particularly relevant concern in the light of the COVID-19 pandemic); and more sustainable, as transportation distances are reduced, less processing is done along the chain, less packaging material is used, and due to the fact that

> SFSC are considered 'shorter' in terms of smaller distances the food travels between producer and consumer, as well as in terms of the smaller number of intermediaries between the farmer and the consumer.

local food systems are presumed to be more compatible with organic farming. It should also be noted here that empirical research is not unequivocally supportive of these assumptions. For example, while it is shown that farmers do have more market power and retain more of the food revenue than in longer chains, SFSCs may not necessarily be more sustainable, as transportation and processing in these chains tend to be less efficient than in high-volume, longer supply chains. Nevertheless, policy initiatives such as the recent EU 'Farm to Fork' Strategy explicitly recommends shorter food supply chains for more positive food system outcomes.

In what contexts does it make sense to consider shorter food supply chains?

There is a sharp distinction between the relevance of this issue for developed economies as opposed to for low- and middle-income countries (LMICs) – different contexts which warrant a different discussion of the merits of SFSCs. The discussion above on the workings of SFSCs and their advantages is most relevant from the perspective of developed economies, where consumers predominantly buy their food at supermarkets with efficient, professionally organised supply chains. Losses in the postharvest chain occur due to unnecessarily discarding of off-spec products, and waste occurs at the end due to a myriad of factors in consumer behaviour (e.g. buying too much, not planning sufficiently). Some would say that food is 'too cheap' in that it does not reflect the true economic, environmental, and social costs of production, and therefore incentivises less careful behaviour regarding food – which is another discussion altogether. Shorter food supply chains in this case would mean consumers omitting the supermarket and buying directly from farmers in the area or through a local intermediary. For affluent consumers, locally produced and procured food can also have additional value, in that they can buy into the story that comes with it and see it as an enhanced food experience.

> Direct interventions in both ends of the chain are likely to be more effective in reducing FLW than prioritizing shorter supply chains as a general measure.

On the other hand, in LMICs, the rural poor already rely to a large extent on short food supply chains, procuring food from nearby farmers. For farmers, this is not a very profitable livelihood, as the spending power of these consumers is limited. In these countries, long supply chains supply the rapidly growing cities with food, either domestically produced or imported. For domestic farmers, urban markets may be more profitable when they can sell their food to higher-income urban residents. However, these rural-urban chains are characterised by a number of issues that reduce their efficiency. First, infrastructure in LMICs is generally limited, especially in more remote areas, making transportation costly and in-transit food losses more likely. Secondly, transaction costs are high since these long supply chains have a large number of smaller (often informal) intermediaries, each of which takes part of the profit, the farmer's share of which is very limited. Third, as a result of the large number of intermediaries, farmers obtain less information about market and demand conditions in cities, and cannot adjust production accordingly. The resulting mismatches between demand and supply lead to over- or underproduction, food loss and waste, unmet urban food demand, and foregone farmer profits.

In this case, farmers and urban populations would benefit from shortening supply chains in terms of reducing the intermediate links between producer and consumer. In terms of physical supply chain length, opportunities for farmers may in fact be more abundant when they can reach more affluent consumers farther away, in domestic urban markets or by exporting to higher-income regions. The recommendation for urban and peri-urban farming would mostly address the issue of urban food and nutrition security, with expected reduced losses (through shorter distances and stronger market linkages) as an added benefit. From the perspective of the farmer, more value can potentially be gained from longer-distance chains, but these chains would need to be more efficiently organised with fewer intermediaries, thereby allowing them to effectively access more distant, higher-value markets – and reap the benefits accordingly. These longer chains may still have reduced FLW due to the lower number of intermediaries, and any loss-reducing interventions producers are able to implement when they can increase their income by accessing higher-value markets.

Conclusions – To shorten or not to shorten?

Shortening food supply chains – in terms of distance and/or the number of supply chain links – can serve to reduce FLW through several mechanisms, along with implications for other food system outcomes, and sometimes tradeoffs between several outcomes. Whether it should be seen as an absolutely necessary strategy to reduce FLW remains an open question for two reasons.

First of all, evidence on the effects of shortening food supply chains is limited, ambiguous, and strongly context-dependent. It does have a strong intuitive appeal due to the various ways in which it can – hypothetically – reduce losses and waste. These mechanisms seem more straightforwardly relevant in high-income countries, where affluent consumers can relatively easily procure local food as a high-valued alternative to supermarket chains. In LMICs, issues of market access, market linkages, food and nutrition security, and rural livelihoods are all important outcomes that should factor into the consideration. Farmers may actually benefit from longer supply chains through which they can access higher-value markets. While there may be potential for efficiency gains by reducing the number of intermediaries, this may not be possible when poor communications and physical infrastructure is the root cause of fragmented supply chains.

Secondly, supply chain length is far from the only determinant of losses and waste. In fact, the most important loss and waste hotspots in food supply chains are primary production (pre-harvest and on-farm postharvest losses) and consumption (food waste in households, retail, and foodservice). Aside from some hypothesized, but debatable indirect effects (e.g. farmers can produce more sustainably when chains are short and consumers are less wasteful with local produce, but on the other hand powerful intermediaries in longer chains can support farmers to improve their operations), supply chain length does not directly impact on FLW occurring during the production nor in the consumption stage. As a result, direct interventions on both ends of the chain are likely to be more effective in reducing FLW than prioritising shorter supply chains as a general measure.

In the discussion on SFSCs, food loss and waste is only one of several food system outcomes that can be affected by shortening supply chains. When discussing whether it is a worthwhile undertaking, all these outcomes – and the tradeoffs between them – should be considered. This discussion on the pros and cons of specific food system transformation pathways should be solidly founded on a consideration of which outcomes we value, and what kind of food system we want to be a part of.

Suggested reading

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Chapter 10.

Ensuring accessibility of insect-based feed to small-scale fish farmers in Kenya and Uganda

Katrine Soma

Insect-based feed has the potential to advance the use of existing protein sources exponentially. As with any innovative development, one of the main challenges is to ensure its availability to low-income groups. The small-scale fish farmers in Kenya would be highly interested, but have not yet transitioned due to low access to affordable high-quality insect-based feed.

The Black Soldier Flies Larvae (BSFL) gives a great opportunity to small-scale fish farming

In Sub-Saharan Africa the population may increase from 1.15 billion to 3.8 billion from 2022 to 2100. An increase in the demand for animal-derived protein sources for human foods and animal feeds will take place, while natural resources are threatened by degradation, and large numbers of people are living below the poverty line. An increase in the living standards of low- and medium-income groups will therefore require circular economy solutions with a re-use of waste and a shift towards the consumption of sustainable sources of protein, such as insects. In a circular animal system, the total protein supply is increased without the need for additional resources. This is a possibility when safeguarding zero waste, upcycling proteins to the maximal use and making use of microorganisms, insects or other animals to upcycle resources that are not suitable for human consumption.

In Figure 19, the interaction and influences within a food system are demonstrated. The aim of this chapter is to investigate business models that can enhance the accessibility of innovative solutions of insect-based feed. Ensuring the resilience and sustainability of socio-economic and environmental drivers, and favourable outcomes of the food systems – such as food security, inclusiveness and equitable benefits, safe and healthy diets, sustainability and resiliency – are inherently accounted for in the strategies investigated.

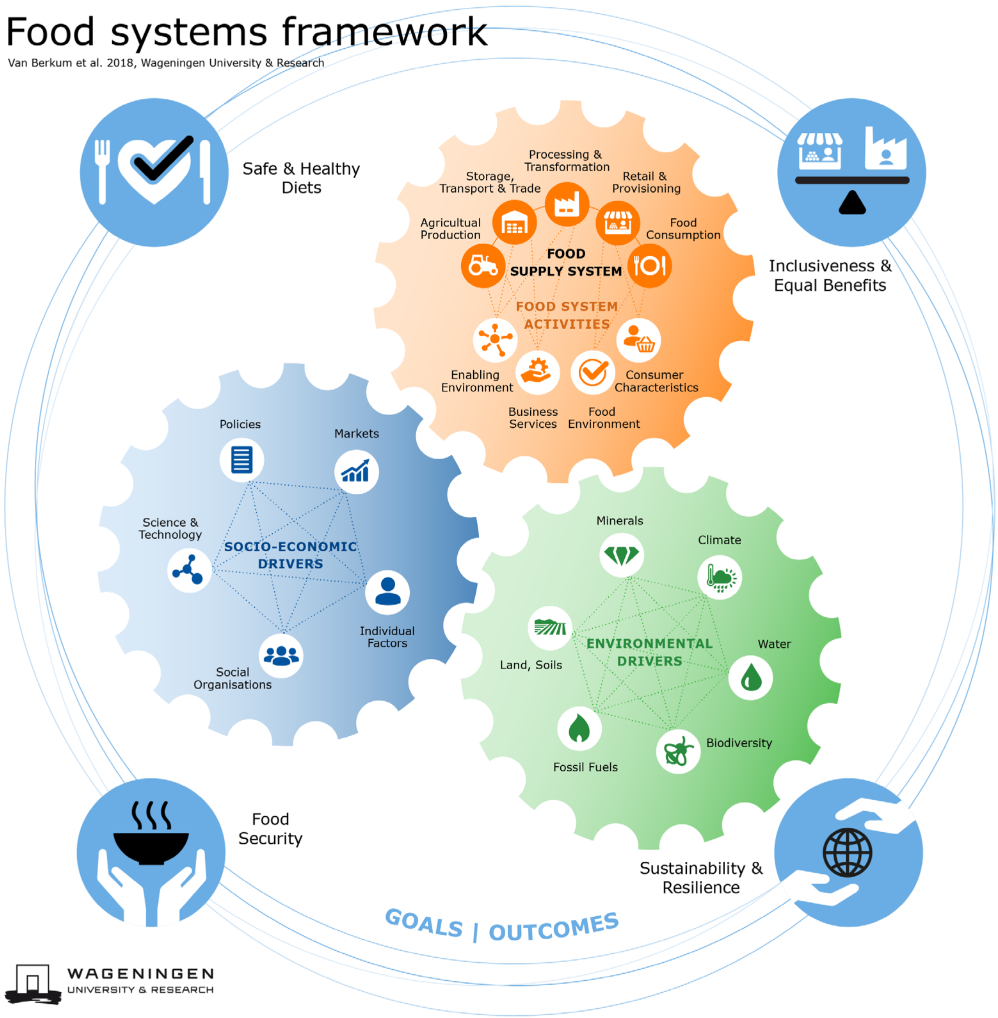

Figure 19. A food system framework is applied when focussing on how the innovation of insect-based feed in fish food production systems interrelates with socio-economic and environmental drivers, with ultimate consequences on all the outcomes (i.e., food security, inclusiveness and equitable benefits, safe and healthy diets as well as sustainability and resilience)

The black soldier fly larva (BSFL) (*Hermetia illucens*) possesses a series of qualities allowing it to convert all types of organic waste into animal feed. The BSFL is suited to providing protein to the diet of a variety of animals, including poultry, pigs, and fish. During larval stages, the BSFL has a great appetite for organic waste, including everything that is beginning to rot. The BSFL have been shown to effectively digest a wide range of organic waste products such as offal, kitchen waste, fruit and vegetable waste, and even chicken manure.

The BSFL has several benefits. First, it is easy to harvest. In the last stage of the BSFL's life cycle, the larva develops a large fat store, empties its gut, and then seeks a place away from the waste to pupate, which makes it simple to collect the larvae. Second, after the food waste has been processed by the BSFL, the excreted biomass is nutrient-rich, low-odour humus that can be added to soils as an amendment to increase organic matter and fertility. However, there are various challenges to formulating feed based on BSFL, which must be dealt with sufficiently, including the presence of chitin, as well as high fat levels compared with regular high quality fish meal pellets.

Newly hatched larvae have a dull white to cream colour and are about 1.8 mm long. A larva goes through five larval stages and completes development between 13 - 18 days under favourable conditions. Optimal moisture content for the feed must be met (60%-90%), as well as optimal temperatures for efficient processing (27-33°C). The BSFL is reared under shade, as they bury themselves in the substrate when exposed to light. When the BSFL has grown to roughly 27 mm in length and 6 mm in width, they have a pale white colour with a small black head containing their mouthparts. It takes about six months for a larva to reach maturity as a black soldier fly (BSF).

It is highly recommended and encouraged to introduce the BSFL into Sub-Saharan African farming practices, as is it a source of sustainable feed ingredients that can improve circularity in the animal feed chain.

Reducing the feed costs will increase the wellbeing of small-scale fish farmers tremendously

The aquaculture sector in Kenya is very diverse, including cages located on lakes and dams and ponds on agricultural land. In the years 2009-2010 a governmental programme called the Economic Stimulus Programme (ESP) intended to enhance the Kenyan economy towards long-term economic growth. While the programme has been confronted with criticism, it has also stimulated extended fish pond farming. Small-scale farms who intended to transition into commercial fish farming were the main beneficiaries of the programme.

Some 50,000 pond fish farmers operate across Kenya, of which most are commercialised only at low or medium levels. An average small-scale fish farm operates with one, two or three ponds of about 300m3. The pond fish farmers mostly cultivate Nile tilapia and African catfish. Although the pond fish farming demands commercial feed, this may be financially and infrastructurally out of reach, resulting in use of either homemade fish feeds, pig pellets and or poultry feed (growers mash and layers mash), often to the detriment of the business. The lowest-income fish farmers use their own labour, and consume the fish in the household, while others sell at the farm gates to neighbours or other customers. Given low opportunities for making choices of investments due to the low availability of micro-credits, these businesses often operate below optimal performance and may incur losses. A typical business model of small-scale fish farmers is shown in Table 1.

Yearly net income		One Pond (€)		Share feed costs
Income	**207 kg per pond * €3 per kg**		**621**	
Variable costs	**Sum of the costs below**		**504**	
Costs feed	*1.7 kg feed per 1 kg fish*207 kg; €1 per kg feed*	*352*		*69%*
Costs fingerlings	*15 KSh per piece per pond with the current stocking rate of 1,000 fingerlings per pond*	*100*		
Operational costs	*Operational costs as share of total variable costs: 10.26%***	*52*		
Net income			**117**	

*This business model is an average based on the Nyeri Fish Farmer Cooperative Society LTD in Kenya, January 2022
**Variable costs include: Labour, marketing, insurance, IT, sales & commissions, permits & local licenses, leasing land, maintenance, overheads.

Table 1. A general business model of the small scale pond fish farmers in Kenya*

For one pond the net income per year is only about €117. Note that the gross income is more than five times that amount: €621. Because the variable costs are relatively high, the net income is low. Of the total variable costs, 69% is spent on feed. The example shows how much impact the feed costs have on the small-scale fish farmers' business models.

Not only the small-scale fish farmers suffer from high feed costs. Figure 2 shows an overview of floating pellet costs as a share of variable costs, based on a sample of 280 pond and cage fish farmers interviewed across the counties Kakamega, Siaya, Nyeri, Kirinyaga and Kiambu in 2018 in a project called 3RKenya. This confirms that the feed costs are relatively high among most fish farmer categories in Kenya.

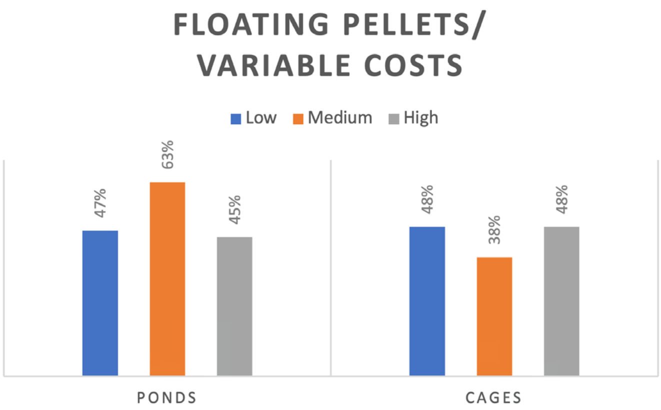

Figure 20. Feed costs for floating pellets as a share of all variable costs to different cage and pond fish farm categories, including low, medium and high commercialisation levels

Alternative BSF feed production system supplying small-scale fish farmers' needs

To date, high quality, expensive feed is imported from, among others, the Netherlands, Norway, Denmark, Israel, Egypt, Mauritius, Uganda, and Ghana. Currently, only 7% of the total amount of fish feed needed in Uganda is locally produced. The remainder consists of imported or home-grown mixtures, often of poor quality, compromising the effectiveness of fish production in Uganda (Khan et al, 2021). This feed still makes use of soya as main protein source, which has been criticised for contributing to natural resource degradation and climate footprint of the industry. When available, fishmeal is the preferred protein ingredient in fish feed, as it is better digestible for fish than soya. Fishmeal is being produced around Lake Victoria, but is of poor quality and usually contaminated with sand, as it is dried on the shores of the lake, making BSF an even more attractive product.

Prices of fish feed are high (see Table 1). Because of the economies of scale, the imported feed can be produced relatively cheaply and is therefore in high demand. High-quality feed is also produced domestically in Kenya (e.g., Sigma Ltd, Unga Feeds Ltd, Lenalia Feeds Ltd). The domestic companies have invested in production systems using insects as a protein source. This is highly welcomed by the fish farmers, although prices remain high, and is positive from an environmental point of view. Existing challenges include problems of oil to deal with when producing the pellets. Still, the domestic supply of high-quality insect-based feed has great potential for the small-scale fish farmers in the future. A first investment in oil extraction in BSF production in Uganda was done in 2021, when Proteen Ltd installed an oil press with which they are producing protein-rich insect meal and insect oil. The protein rich insect meal can be used as a highly suitable source of protein for fish feed, and the insect oil is very beneficial to young animals such as piglets, for which it is highly digestible and boosts the immune system.

Another business model for insect-based feed production in Kenya, and also in Uganda, is targeting the small-scale fish farmers by selling them the baby BSFL. The farmers get an opportunity to earn extra income after having fed the BSFL on waste materials on their farm, and selling the grown out BSFL back to the companies. The farmers also benefit because the waste used to grow the larvae is transformed into high-quality fertiliser. This cooperation between feed producer and fish farmer as business model is still in an early stage but looks promising and full of potential for the future. To date, it has been difficult to produce the BSFL-based feed at affordable prices. Also, instead of selling grown out BSFL back to the company, they prefer to feed their own fish with the grown out larvae. This demonstrates the huge scarcity of affordable feed.

If a BSFL-hatchery production system were run by the small-scale fish farmers themselves, they would not need to share the profit margin with a feed company and it could then be operated at lower costs. Such an insect-based feed production business model could be combined with a fish farming system, or be operated by farmers who decide to concentrate only on BSFL production in the communities. This highly local and circular practice would target the exact needs of the fish farmers by balancing quality and needs, although not providing standards similar to laboratory-made feed. Because the fish farmers do not yet know how to operate a hatchery, and will need some micro-credit to invest, community-based BSFL hatcheries have not yet been scaled to date.

Alternatives	Price	Quality	Quantity	Fit to needs opportunities
Feed companies produce high quality feed	Price is high, with economics of scale lower price for large amounts possible	High quality ensured in large volumes in efficient production systems	Economies of scale allows large amounts	It is possible to mix this feed with other sources to adapt to specific needs
Feed companies cooperate by larvae production on farms	Farmers can earn from larvae, resulting in net reduction in price of feed.	High quality ensured in smaller volumes in efficient production systems	Smaller production volumes than the large scale production	Depends on willingness to sell the larvae back to the company. Farmers also have poultry and pigs to feed.
On farm hatchery and feed production	Price reduction potentials suited to demands by the small scale fish farmers	Quality good enough given needs depending on input availabilities	Small quantities can be distributed according to demands	Feed can be combined with high quality feed, or other farmed ingrediencies such as soya, rice bran, etc.

Table 2. Comparison of feed business models and impacts on small-scale fish farmers in Kenya

Table 2 gives an overview of the main characteristics of the three main BSFL-based feed business alternatives, which could potentially benefit the small-scale fish farmers.

Transitioning towards resilient and sustainable food systems with insect-based feed in pond fish farming

For the small-scale fish farming industry to transition to BSFL-based feed currently brings high costs to the fish farmers. This does not need to be the case in the future. Different opportunities exist for supplying the small-scale fish farmers with affordable protein-rich feed based on BSFL, including feed companies producing high-quality feed, feed companies cooperate by larvae production on farms, or on-farm hatchery and feed production. These alternatives can be combined to achieve optimal solutions to serve the small-scale fish farmers in the future.

Suggested readings:

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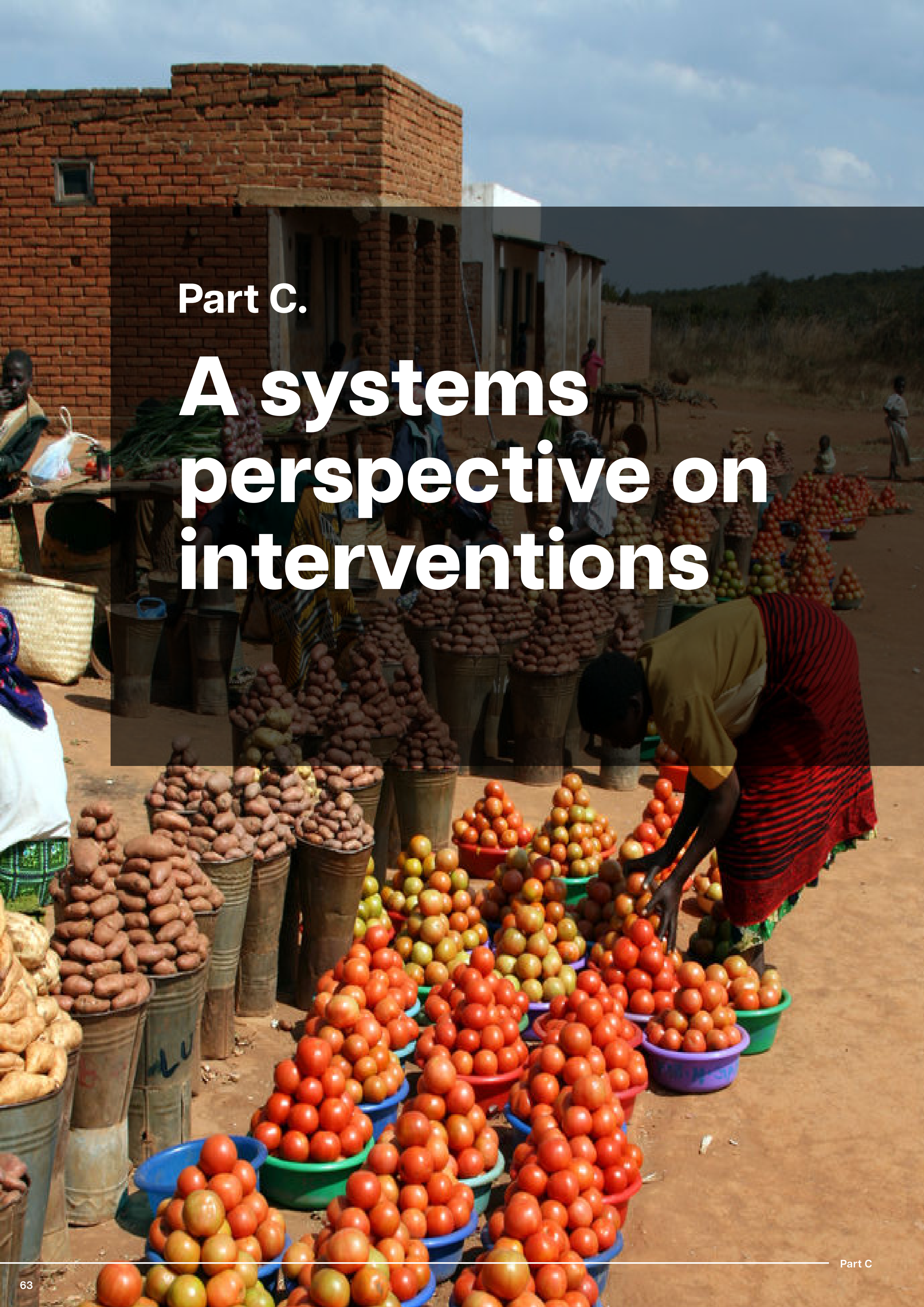

Part C.

A systems perspective on interventions

Chapter 11.

Beyond Technology: key ingredients for FLW reduction strategies

Herman Snel

Addressing FLW at scale will require partnerships and incentives that look beyond production and productivity enhancement to address the overall performance of a food system and its outcomes. Current support for agriculture does not provide adequate incentives to address and mitigate FLW.

The Catch-22 of food losses and waste (FLW) reduction

A little more than ten years ago, statistics revealing the magnitude of the issue of FLW and its effects on the economy and the environment shook the global community. The ensuing wave of investments in research, technology development, and awareness raising have undoubtedly increased our overall understanding of the complexity of FLW and the factors causing FLW. Compared to ten years ago, the global community has got far better insights and intelligence into where and why FLW occurs, how much is lost, how food quality is affected, how stakeholders are affected, the environmental footprint of FLW, etc. A wide array of technological innovations to address FLW have been developed, tested, trialled and validated as being effective and generating a positive return on investment. Although most research on FLW has been predominantly technical in nature, the global community has a much deeper understanding of the mechanisms and issues that cause FLW and the technologies and practices to mitigate FLW.

Regardless of all these efforts, the real-life cases where FLW has been effectively mitigated or reduced remain limited to specific project interventions, particular geographical areas and specific value chains. Considering the evidence on the business case to reduce FLW and the evidence for cost-effective technologies, one can't help wondering why we still see tremendous volumes of safe and nutritious foods being lost or wasted before they are consumed by humans. Is there a mismatch between technology and producers? Is there a lack of incentives? Why are we seemingly locked in a Catch-22 where we are looking for ways to provide healthy and nutritious diets for all whilst reducing the environmental footprint of our food system, yet knowing that there are ample volumes of harvested agricultural products being lost or wasted before they are being consumed?

This chapter argues that FLW is one of the unaccounted and unintended trade-offs resulting from a food system based on metrics of success measured by production and productivity outcomes rather than measured by inclusive socio-economic outcomes, food security, nutrition and environmental outcomes.

Strategies geared towards improved socio-economic outcomes bundle contextually suitable technological innovations (hardware) together with capacity development and strengthened stakeholder collaboration (software), and institutional and policy innovations (orgware). Integrated system transformation approaches stand the best chance of being effective, successful and scalable. Addressing FLW will inevitably change the current rules of the game and will require a behavioural change on behalf of many stakeholders. Considering the impact and benefit that each specific actor incurs from post-harvest losses and loss mitigation measures, support mechanisms and incentives will facilitate the required behavioural change of all stakeholders involved.

Engagement of multiple stakeholders in loss-mitigating strategies and investments is particularly important when addressing FLW in LMIC. In the context of LMIC the majority of qualitative and quantitative food losses can be mitigated to a large extent through adequate production practices, good post-harvest handling practices and temperature control being applied immediately post-harvest. These production, harvest and post-harvest first mile issues account for the largest causes of loss in LMIC supply chains. Together with the constraints smallholder farmers face to access and reach markets creates a context whereby the prices obtained for an agricultural product at the farmgate are often ten times lower than the prices obtained at retail markets. Therefore, investments and additional efforts made at the farm level predominantly benefit value chain stakeholders that are closer to the retail and consumer level and have not invested in on-farm measures to reduce loss. Market-driven, price-based contractual agreements and institutional innovations are needed to support stakeholders to adjust their current behaviour and disrupt the food system dynamics that underlie the current levels of loss and waste. As underscored by the research of Sheahan and Barret (2017), without these types of market and economic incentives, value chain stakeholders lack a real economic incentive to prevent losses and will outweigh individual benefits and costs of interventions over the societal and environmental costs. Addressing food loss and waste requires innovative food system approaches, stakeholder collaboration, context-specific, co-designed, bundled approaches, supported by contractual arrangements and enabling structures that are capable of valuing the real costs and real price of FLW by matching investments that are needed to support the socio-technical transitions that can address FLW in our food system.

Re-configuring global support to agriculture whilst addressing FLW

Gautam et al. (2022) argue that 'Current governmental support for agriculture provides incentives for unsustainable patterns of production and consumption'.

Undoubtedly agricultural productivity has witnessed historical peaks that have had positive effects on food availability, food prices and food markets. Global wheat production levels have never been as high as they were in 2021. Nevertheless, even under these conditions, undernourishment and malnutrition are increasingly gaining ground, affecting millions and millions of people worldwide. Our current food systems include a multitude of hidden costs, which are indirectly carried by the environment, small-scale food producers, landless labourers and consumers.

At a global scale, the food system receives significant support from a wide range of stakeholders. Gautam et al. (2022) assess that the magnitude of total annual support to agriculture provided by 79 countries reaches approximately 638 billion USD. When this figure is added to the numbers provided by the OECD on food aid investments from official development assistance for the year 2019 (4800 million USD) the Catch-22 situation becomes uncomfortably awkward. How is it possible that so much development aid is being invested in our food system, yet food insecurity and malnutrition continues to increase at staggering rates?

It is claimed that 95% of investments in agricultural research are focused on production and productivity enhancement, while 5% of investments are geared towards research to reduce losses. Financial support packages aimed at increasing production and productivity of staples and food security crops abound and are endorsed by both public and private financial institutions. In contrast, tailored financial support packages supporting small-scale producers to invest in loss-mitigating measures and technologies for highly perishable, nutrient-dense commodities destined for domestic and local markets are scarce.

The myopic focus on production and productivity has diverted the attention to a variety of associated food system tradeoffs. This is evident for the case of FLW, which has only recently been gaining momentum in research and policy debate. The indirect and associated impacts of FLW related to the social, environmental and economic food system input loss and resource use inefficiencies are increasingly being understood in relation to the costs and footprint that it generates.

A review of post-harvest loss reduction interventions that looked at 22 food crops across 57 countries (Stathers et al., 2020) concludes that most of the studies and interventions focus on cereals and roots and tubers. In contrast, nutrient-dense crops - such as legumes, fruits and vegetables - have received far less attention. The review highlights that most interventions and studies focus on technologies, tools and equipment. In contrast, loss-reducing interventions and strategies that focus on value chain organisation, handling skills, packing and packaging, transportation losses or retail losses, infrastructure, policies, or financial and market driven incentives have received minimal attention from researchers, policymakers and practitioners.

From the large number of studies and interventions that were reviewed in this study, only 13 per cent go beyond measurements of physical or quality losses (in weight or percentages) to consider the associated impacts of loss-reducing measures and interventions on income, nutrition or the environment. Of these 13 per cent, the majority focussed on the economic impact; the social and environmental impact of loss-reducing measures has largely been overlooked in research and policy documents.

Not only should the attention of loss reduction efforts progressively include perishable and nutrient-dense crops, but in addition, the metrics and indicators that we utilise to assess the success of food systems should shift their focus to production and productivity in order to integrate indicators that relate to the socio-economic outcomes of the food system, the nutrition and food security outcomes and the environmental outcomes.

This situation requires, as is argued by the research from the Gautam et al. (2022), "repurposing agricultural policies and support to transform agriculture and food systems to better serve the health of people, economies, and the planet."

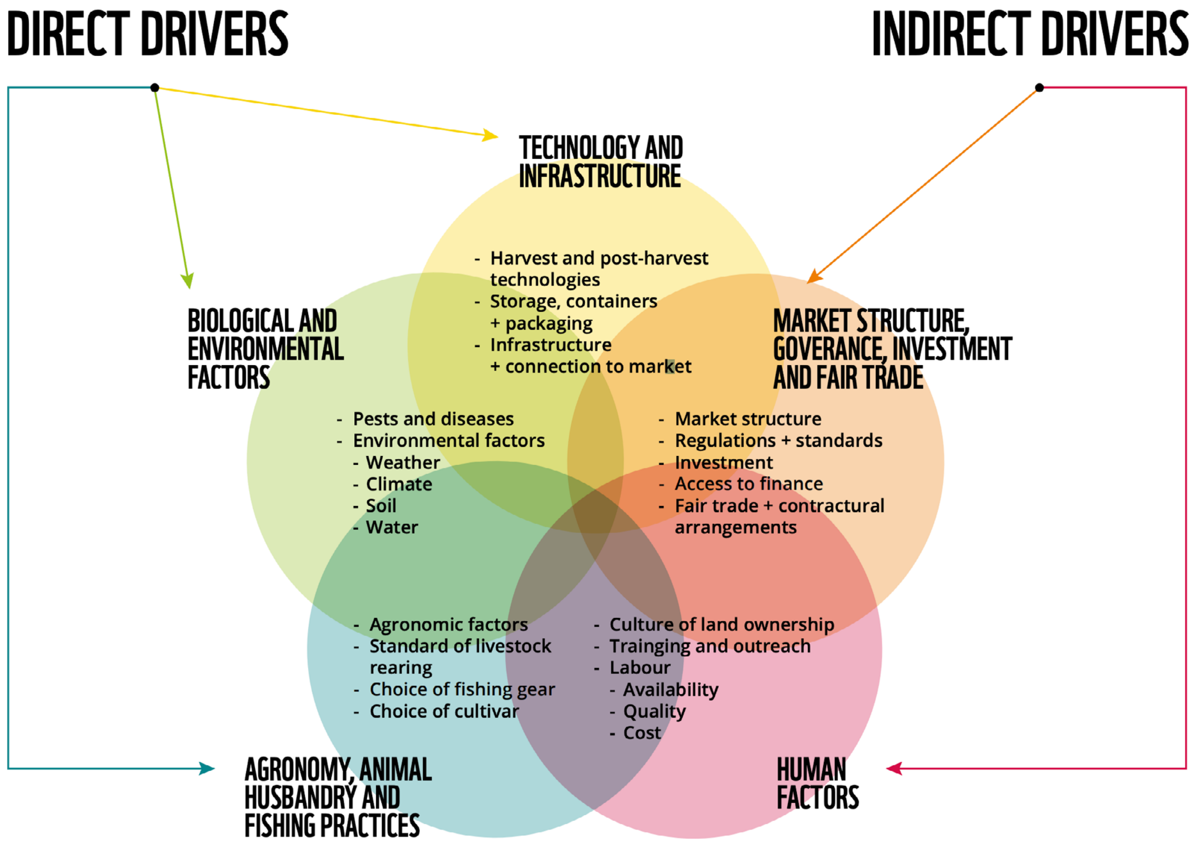

Figure 21. summary of direct and indirect factors driving FLW (Source WWF, 2021)

Understanding the drivers of FLW – to design bundled FLW reduction strategies

Strategies to address FLW require bundled and integrated Strategies to address FLW require bundled and integrated reduction strategies that look at FLW from a food system perspective. As mentioned, currently most investments in agriculture are all geared to support production and productivity. Only a very small portion of these investments are designed to address and mitigate FLW.

Agronomic practices, biophysical conditions and technology factors all indirectly and directly affect FLW and have attracted most of the attention from research and interventions. In contrast, the indirect drivers affecting FLW (see Figure 1), namely the human factors, market structure, investment factors and food system governance factors, have received very little attention, even though they have proven to be key enablers or inhibitors for effective FLW reduction.

Designing strategies and pathways to address FLW requires in-depth understanding of the context-specific drivers (direct and indirect) and the root causes of FLW in a specific food system, sector, supply chain, geography and market.

Soethoudt et al. (2021) delineate six types of FLW-reducing interventions implemented in LMIC:

1. **Technology** – Physical tools or equipment
2. **Finance & investment** – Funding, credit, insurance and other financial products and services
3. **Best Practices** – Changing processes or practices based on knowledge of how to reduce FLW
4. **Organisation** – Coordination inside food chains
5. **Policy** – Government policy affecting the incentive structure and enabling environment
6. **Economics** – Markets and market linkages, economic decision-making

They underscore the need to design customised FLW-reduction strategies that bundle interventions in the mentioned domains for specific value chains, stakeholder settings and geographical contexts.

Bundling and integrating various intervention types, effective FLW-reduction strategies are implemented through collaborative partnerships. A wide diversity of food system stakeholders, including producers, consumers, service providers, vendors, researchers, civil society organisations and policy makers must collectively take action and change their behaviour in order to reduce and mitigate FLW.

Multi-actor and multi-sectoral governance should ensure effective orchestration and coordination of the strategies that integrate not only the agricultural sector, but also the health sector, economic development and employment generation, and many other sectors and domains.

Integrated strategies to reduce loss should be designed to address the root causes of loss and bundle interventions for four specific stages of the food supply chain:

A. **Farm stage**
B. **Transport and distribution stage**
C. **Retail stage**
D. **Consumer stage**

Incentives can help support the required behavioural change and associated investments required to mitigate and reduce losses. Tailored support mechanisms are required for different stakeholders and stages of intervention. Upstream stakeholders, require support that enable them to access, engage and invest in farm-level FLW-reducing measures and technologies. Mid- and downstream stakeholders need to invest in loss-reducing measures and technologies during handling and storage in order to not only address transportation losses but also retail losses at wet markets.

Measuring the impact of FLW-reducing investments and the food system tradeoffs

If we want to really address FLW, there is a fundamental need to recalibrate the focus and ambition of our FLW reducing efforts.

It is important that FLW reduction efforts target the right metrics. Investments to reduce FLW must move beyond measuring percentages of loss to include indicators that underscore the rationale for the intervention.

In contrast to the current myopic focus on single-stage FLW reduction efforts, efforts must consider how and to what degree they can positively influence food system outcomes and outcome indicators. The goal should not be focussed exclusively on reducing FLW percentages or increasing production and productivity, but also on increasing the affordability and accessibility to healthy and nutritious diets for vulnerable population groups. Alternatively, the focus of FLW reduction efforts could be to generate off-farm employment opportunities, to improve land and water use efficiency in the food system, or any other food system outcome. Currently most if not all FLW-reducing policy efforts focus on reducing percentages of FLW at specific supply chain stages.

Cattaneo et al. (2021) argue that FLW reduction strategies must be designed on the premise that they will reduce FLW levels, providing positive impact for food system outcomes, taking into consideration the possible trade-offs and unintended consequences of the interventions.

There is a knowledge gap regarding the direct and indirect impact of FLW mitigation and prevention. Little is known about the impact of loss prevention on the income of a small-scale farmer, and little is known regarding the impact of loss prevention on the availability and affordability of nutrient dense foods and the related nutritional status of rural and urban consumers in LMIC. This is a domain open for research to learn more about the environmental impact of FLW mitigation measures such as cold chains, cooled transport etc.

Any effective FLW reduction strategy and measure must therefore also include rigorous M&E exercises that can inform policy making and the design of appropriate support mechanisms and measures.

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Chapter 12.

Mobilising informal businesses to reduce food losses and waste

Bart de Steenhuijsen Piters

Food loss and waste (FLW) in food systems in LMIC occurs mainly in midstream value chain operations, which are dominated by small, informal businesses. Conventional policies and incentives fail to motivate these actors to address these problems. As such, we need novel ways to mobilise the innovation and scaling capacity of informal businesses to reduce food loss and waste. This in turn requires that policy makers, investors and other stakeholders think more 'out of the box' and apply reverse thinking in their quest for ways to reach out and include the informal businesses.

Informal food supply chains are effective but rarely efficient

The FAO (2011) estimates that roughly one-third of the physical mass of all food is lost or wasted around the world. In SSA, the estimate is roughly 37 per cent or 120–170 kg/year per capita. A report by the World Bank (in: Affognon et al., 2015) revealed that, each year, significant volumes of food are lost after harvest in sub-Saharan Africa (SSA), the value of which is estimated at USD 4 billion for grains alone. The report demonstrates that this magnitude of food loss equates to the value of annual cereal imports to SSA. In addition, such losses are estimated to be equivalent to the annual caloric requirement of 48 million people. Postharvest fruit and vegetable losses in Sub Saharan Africa are estimated to be as high as 30-80% - higher than in southeast Asia, where they range from 11-50% (de Steenhuijsen Piters et al, 2021).

The causes of these significant losses and waste in LMIC find their origin in food supply system operations between farm and retail. These operations are referred to as midstream supply chain activities, which include trade, transport, storage and processing. In LMIC and with special reference to fruits and vegetables, evidence indicates that 90% or more of all domestically produced volumes are traded through informal midstream supply chain operations (de Steenhuijsen Piters et al., 2021). These supply chains can be considered effective, as they are capable of supplying consumers with foods, irrespective of the many financial and logistical risks and inconducive conditions. But they cannot be considered efficient. Efficiency is an effect of the smooth operating of the supply chains, resulting in low post-harvest losses and waste, with actors being well-aligned, and contributing to low transaction risks and associated costs.

The biggest contributors to inefficiency in informal food supply chains include the high seasonality of production, limited market integration of producers, poor infrastructure, high uncertainty levels on sales and prices, and a lack of standardized grading and weighing systems. Besides inefficient, many informal food value chains in LMIC are not equitable in terms of fair pricing as a function of asset inputs, such as time and labour. This is particularly observed for women actors in the supply chains.

Informality is often seen as an obstacle to upgrading supply chains and thereby enhancing their efficiency. Yet, pro-formalisation strategies have had a limited effect on informal business (World Bank, 2020). Attempts to formalise the informal economic sectors in LMIC through policy and interventions have shown very mixed results and brought limited knowledge on how to address informality in a systematic way (Marusic et al., 2020).

Views on the informal economy

The informal sector includes all businesses, workers and activities operating outside the legal and regulatory systems. The scale of the informal economy in LMIC accounts for 25 to 40% of GDP, but could well be even higher when referring to food supply chains. In general, there are four views (Marusic et al., 2020) explaining why informality occurs:

- Informal businesses are 'excluded' due to high entry costs or businesses remain intentionally 'small' to avoid detection by authorities.
- Businesses voluntarily choose to exit the formal economy after assessing the costs and benefits of formalisation.
- There are not enough jobs in the formal economy, so the informal economy is a necessary space for overflow workers and small businesses.
- The informal economy is a subordinate complement to the formal economy, providing the latter with cheap inputs, notably labour, and flexibility by operating in an unregulated manner.

Whatever view one espouses, informal businesses in LMIC tend not to respond to conventional policies, incentives and other measures to regulate and legalise them. Sometimes, enforcement of policies has been successful, but has subsequently proven to result in limited or no benefits to the small businesses. In many LMIC, high levels of taxation, corruption on the part of government officials and the inadequacy or absence of public services imply that the disadvantages of formalisation outweigh the economic and financial benefits. It was even found that the effect of corruption on inequality declines as the size of the informal sector increases (Young and Crush, 2019). Furthermore, in Pakistan it was observed that higher perceived levels of public sector corruption increase the likelihood of a business operating in informality (Marusic et al., 2020). To conclude, efforts to reduce postharvest food losses and waste in LMIC would actually profit from accepting the informality of businesses involved and should seek novel ways to reach and engage them. Conventional approaches and incentives, such as tax exemption and access to loans, simply do not reach informal businesses, as they do not pay taxes and have no legal status nor collateral. In order to identify novel measures to which informal businesses are susceptible, we first have to understand these informal businesses better: who are they?

Some key features of midstream, informal businesses

At present, there are significant gaps in the knowledge base about the character, operation, and roles of the informal food sector; a pre-requisite for sound and supportive governance (Young and Crush, 2019). Informal markets involve informal businesses, mainly non-regulated standards, and a mix of formal and informal agreements, often based on social networks, faith or kinship relations. Besides the fact that they operate outside formal structures, informal businesses have several properties in common. What emerges from literature are the following characteristics:

- They are mainly small and organised according to principles other than only economic ones.
- They are often organised in strong, yet informal networks ruled by distinct norms and values.
- Together, they form more or less coherent alternatives to formal governance structures.
- Informal businesses can be exclusive or inclusive, more or less gender biased, and having positive or negative impacts on other food system stakeholders (and their livelihoods).
- Informal businesses are deeply rooted and embedded in their socio-economic and political environments, and are therefore generally considered resilient and flexible.

Informal businesses and their networks are often based on other motives besides economic interests, such as kinship and faith. These motives to build a business or engage in networks create the social capital and related levels of trust that are needed to do more than incidental business. This characteristic of informal businesses has also been found to limit their expansion and scale, however, as the accumulation of capital assets may be hampered by social expenditures and relationships may prevail over professional capacities in human resource management.

From the Global Scoping Study on Fruits and Vegetables (de Steenhuijsen Piters et al., 2021) it was concluded that informal traders invest considerable resources in developing and maintaining personal relationships, obtaining market information and traveling to farmers to check potential supply quantity and quality; if the farmer has already sold to someone else, the trader cannot recuperate the investment. This problem is exacerbated when there are many traders and few farmers during the low production season and vice versa; farmers in remote locations may only be able to sell produce for a relatively low price during peak season since traders are not always in the vicinity.

In informal markets, fruit and vegetable quality is generally graded by appearance, with no standardised quality grades. Weighing traded produce is rare, and instead, units of packing materials (e.g. basket, bags, sacks) are used. The lack of standardised packing, grading and weighing results in disputes and adds to transaction risk, resulting in higher consumer prices. For example, in Nigeria, unripe tomatoes are often packed at the bottom of raffia baskets, while the best quality tomatoes are packed on top; traders anticipate these practices by farmers and compensate accordingly.

Key findings from the Global Scoping Study on Fruits and Vegetables

- Fruits and vegetables are in many LMIC unaffordable and often unavailable to poorer segments of consumers.
- Informal businesses dominate the supply chains, and they are effective but not efficient.
- Most fruit and vegetable loss and waste occur due to seasonality in production (oversupply) and during midstream operations.
- Common responses including processing of oversupply and cold storage are not economically feasible and have mainly failed to resolve the problem.
- Feasible options to reduce loss and waste of fruits and vegetables include: shortening of supply chains (focusing on peri-urban fruit and vegetable production), promoting more demand (consumer) driven production, and diversifying supplies.
- These options all require the prominent engagement and involvement of informal midstream and retail actors, who have the capacity to communicate consumer needs downstream the supply chains and innovate products and delivery models, meeting new consumer demands.
- Shortening supply chains and involving informal midstream and retail actors does not require major investments in logistics or infrastructure. Moreover, they offer better options for the economic integration of women and youth compared to long supply chains.

A key role for small, informal businesses in food losses and waste reduction

If properly managed, the informal food sector has the potential to play a key role in the promotion of food security, inclusive growth, and poverty reduction. Most obviously, it can play a vital role in urban food security by providing consumers (particularly the urban poor) with an accessible, affordable, and reliable source of food, filling large gaps in the market left by formal food retailers (Young and Crush, 2019). More specifically, informal midstream businesses can contribute to reducing FLW.

Based on what is documented in literature, four approaches (Marusic et al., 2020) can be distinguished which reflect some level of evidence of their effectiveness:

1. **Connecting to informal clusters, business networks, informal associations, syndicates or other prevalent forms of organisation.** This approach acknowledges the importance of informal businesses and invites them to join agenda setting for changes in the food system that contribute to reducing food losses and waste.
2. **Enhancing insights in informal business behaviour.** This approach allows for the identification of incentives that are effective in motivating informal businesses to change practices, and invest in or innovate products and product delivery.
3. **Supporting informal businesses and business organisations without the explicit goal of formalisation.** An illustrative example is the successful introduction of plastic crates in Nigerian tomatoes value chains, which reduce loss and waste and have been widely adopted by informal traders. This approach works to increase understanding of the kind of support an informal business needs, and how this may help reduce FLW. The informal sector can be targeted and supported in many ways, including through innovative modes of financing, extending social protections, providing business trainings, or improved public service delivery.
4. **Providing simplified, temporary, legal status.** This could provide the informal business with a grace period during which it can receive the benefits of formalisation, when deemed useful, without the associated disadvantages.

Although evidence on the effectiveness of the above-mentioned approaches is still scarce, lessons learnt indicate that any attempt involving informal business in reducing FLW should start, first and foremost, with a prior acknowledgement of their importance, and with making them visible: it is often not obvious who they are, nor how to approach them. Frequent reference is made to the informal sector as the 'hidden middle' (Liverpool-Tasie et al., 2017) which is more a disqualification of formal policies to recognise their importance, than a qualification of informal businesses in LMIC food systems. Yet, not all informal businesses and their modes of organisation are suitable to engage in processes of improving food system outcomes, such as reducing FLW. For that matter, their credibility and ability to contribute to food system outcomes must be ascertained. Informal syndicates based on very unequal power relations and often strong political lobby capacities may not qualify for addressing questions of increasing public good creation. Besides such checks, understanding must be deepened of their internal dynamics, mechanisms and service delivery systems, as well as sensitivity to incentives and policy measures. Joint agenda setting to examine food losses and waste, their causalities, and actor involvement is needed to assess the feasibility of plausible innovations. These need to be jointly tested, monitored and evaluated, including the values and expectations by the informal businesses.

To conclude: formal institutions need to cross the line into informality

Reducing FLW in LMIC food systems requires new thinking about food systems, their drivers and key actors for addressing food system failures, such as FLW. Small, informal businesses can address these problems, if acknowledged, approached and supported by dedicated incentives and policy measures. This requires formal institutions to cross the line into informality, and that is not easy, yet very much needed. In this unknown and often unpredictable environment, it is important to assess a priori the credibility and ability of informal actors to deliver on food system outcomes. This is particularly important when pursuing public goods, such as making healthy foods more available and accessible to low-income households. Public and informal private sector players can create functional liaisons for this purpose, but this requires building mutual trust where this may not have historically evolved. And that may be the biggest challenge to mobilising informal businesses to reducing food loss and waste.

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Chapter 13.

Concluding remarks

Sanne Stroosnijder and Bob Castelein

This concludes this journey into the world's food systems in search of losses, waste and ways to solve them, and hopefully marks the start of subsequent successful journeys into this relevant domain. We started from a general food systems perspective and a vast number of recommendations for strategies to reduce food loss and waste (FLW) and accelerate the transition towards sustainable food systems, and took up the question of how these recommendations can be implemented in food systems in such a way that they achieve sustainable impact and contribute to sustainable development outcomes across the board. FLW is not an isolated problem and should not be addressed as such, but should be addressed in the context of a broader transition towards more sustainable and equitable food systems that provide safe and healthy foods for everyone.

The contributions in this volume have highlighted several very diverse possible pathways towards this goal. Within this diversity, a common thread that ties the various chapters together is the recognition of diversity in food systems, with profound implications for any FLW-related intervention pathway proposed:

- Intervention strategies need to be tailored to the local context in order to be successful.
- Decisionmakers should beware of side effects - both intended and unintended (economic, distributional and environmental) consequences of interventions.
- Successful intervention strategies require the participation of all relevant actors, even if these are hard to reach or to mobilise, such as the informal sector.
- Technology can and should be part of the solution, and in addition, this solution should be supported by the right incentives, stakeholder acceptance and a feasible business case.

The way forward is not clear-cut, as illustrated by several points of tension between the angles taken in the different chapters. On a profound level, conceptual frameworks (e.g. food system frameworks, valorisation hierarchies) are very necessary to structure thinking, to understand the context in which FLW happens, and to inform and direct action. However, at the same time, these should be flexible enough to be actionable, which again invites discussion that may not lead us any closer to meaningful action. Policymakers, financiers and researchers increasingly call for a 'systems lens' to be applied to select the best intervention pathways, which suits their need for a view on systemic issues that can be addressed with profound solutions. The other side of this medal is that while FLW is a global problem, it requires local solutions to be implemented in the physical activities and processes of the food supply chain and requires cooperation from the actors involved. The need for adaptive and tailored solutions to fit specific contexts seems at odds with calls for systemic transformation – the key question here is how to scale up small local successes to achieve systemic impact.

Here it is crucial to keep in mind that FLW is far from the only issue on the agenda when it comes to food system transformations. Although it is a systemic issue that should be addressed, other food system outcomes related to food and nutrition security, environmental sustainability, economic development and inclusiveness should be improved accordingly as well. At first glance, mitigating

FLW seems to contribute to progress on these outcomes: More food that is produced can reach its consumers, less resources are wasted producing food that would be lost or wasted, and opportunities for economic value increase when food is saved from being lost or wasted. However, when considering these outcomes in a food system with myriad stakeholders, interests, influences, policy goals and linkages, it yields a complex distributional puzzle of who should make which investments and who benefits from this. If not mitigated, this leads to a pattern of lock-in in which no meaningful change happens.

This requires technology and the organisational enablers that allow this technology to be used towards impact, as well as shifts in behaviour on the part of all actors in the food system. In the domain of innovation and solution development, it is a challenge to balance the need for tailored solutions that are appropriate for the user and its context, as well as the need for technology to be made accessible to the greatest possible group of potential users. In addition to the right technology, the right boundary conditions are absolutely necessary in order to realise sustainable impact. Therefore, the key to any transition pathway is to get the incentives right, stimulate behavioural change, and create an enabling environment that mobilises and empowers actors to set change in motion in local contexts.

Call to action

More than a reflection on the takeaways from the work in this volume, this concluding section should be read as a call to action. SDG Target 12.3 calls for a 50% reduction of food waste and for further significant reductions in food losses across the chain by 2030. In the context of the SDGs, FLW is not an isolated issue, but connected to global socio-economic and environmental outcomes that should be improved as well. With this deadline and broader view, the clock is ticking and the urgency to take action and realise meaningful and sustained impact grows by the day. Therefore, the following is necessary:

- **There is a great potential role for applied research in improving food supply systems.** Aside from further optimising food supply chains in developed economies, we should also increase efforts to reduce FLW in LMIC countries, where much is still to be gained in terms of reducing losses and waste.
- **Making science-based recommendations actionable.** This volume gives examples of the type of thinking needed to adapt general recommendations to the specific food system context in which action has to be taken. There is no shortage of ideas regarding what may work, but translating these into impact in the food system requires bottom-up initiatives to realize 'small wins' as well as more systemic efforts to develop strategies for scaling and accelerating successes.
- **For all actors this involves stepping out of their comfort zone in some ways.** As discussed in this volume, for example, policy makers, civil servants, and funding bodies need to work with and facilitate actors, also in the informal sector, in ways that they are not used to, and researchers should become more actively involved in the actual practices of reducing FLW.
- **Fundamentally, collaboration is key.** Rather than wait for one game-changing development, all of us (as food system actors) should contribute to changing the game – with bottom-up actions of small steps and trial-and-error with the potential to catalyse wider developments, and by getting the political and economic conditions right for sustainable change.

Within Wageningen University and Research we consider ourselves as working at the forefront of finding solutions for the myriad challenges in our food system, from driving the technological innovations that improve agricultural and postharvest practices and processes, to developing the organisational models needed to align and mobilise actors. Fortunately, we are far from alone in doing this, working with numerous partners in the private sector, government organizations, and NGOs. Together we also continuously develop the future research agenda on this issue – looking towards future science-based pathways that are yet to be discovered, explored, and put into action. Examples of 'new' topics currently gaining momentum include the role of biodiversity in food systems, just systems transitions, and models to make food systems truly circular (including for instance the role of insects). Through working on this, we are eager to keep adding new chapters to this present collection, addressing a broader range of perspectives and pathways. We invite interested parties to make themselves known to the editors of this volume.

In closing this volume, we hope to inspire any reader to take a greater interest in our food system and the ways to make this more sustainable and equitable. Systemic change starts with small steps, and progresses with numerous more small steps. We invite all to think about the food system you want to be a part of, and how you can contribute to making this happen.

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A journey into the world's food systems in search of losses, waste and ways to solve them

Food loss and waste is a major problem: An estimated one-third of all food produced worldwide is lost or wasted somewhere between farm and fork. Mitigating food loss and waste is an important pathway towards accessible and healthy diets, more sustainable production and consumption, and more economic possibilities for actors in the food chain. General recommendations abound on how to achieve this, but implementation of these ideas in real-world food systems is rarely straightforward. In this volume, experts from numerous domains explore how high-level FLW recommendations can be translated into concrete actions, solutions, and pathways. The chapters highlight (new) scientific insights and practice-oriented research pointing the way forward from what should happen to how it can be done in order to achieve more sustainable food systems.