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Reducing food loss and waste: Five challenges for policy and research

Andrea Cattaneo^{a,*}, Marco V. Sánchez^a, Máximo Torero^a, Rob Vos^b

^a Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy

^b International Food Policy Research Institute (IFPRI), 1201 Eye St., NW, Washington D.C. 20005, USA

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ABSTRACT

Despite broad agreement in policy circles on the need to reduce food loss and waste (FLW), considerable gaps in information still exist. This paper identifies policy-relevant information gaps, summarizes recent research that tries to fill these gaps and identifies five challenges for researchers, policymakers and practitioners in reducing FLW. The five challenges identified are: (i) measuring and monitoring FLW, (ii) assessing benefits and costs of FLW reduction and the tradeoffs involved, (iii) designing FLW-related policies and interventions under limited information, (iv) understanding how interactions between stages along food value chain and across countries affect outcomes of FLW reduction efforts, (v) preparing for income transitions and the shifting relative importance of losses and waste as economies develop.

1. Introduction

The last decade has seen an exponential increase in interest on the issue of food loss and waste (FLW), in policy circles, academia, and even the private sector. The increase in publications has led to a number of different definitions of FLW, depending on the focus of the publication. For the purpose of this article, food loss and waste is defined as the decrease in quantity or quality of food along the food supply chain (FAO, 2019). Quantitative FLW refers to food that exits the food supply chain, while qualitative FLW refers to the decrease in food attributes that reduces its value in terms of intended use. Following FAO, in practice food losses are considered as occurring along the food supply chain from harvest (or slaughter/catch) up to, but not including, the retail level. Food waste, on the other hand, occurs at the retail and consumption level. This definition aligns with the distinction implicit in SDG Target 12.3, which focuses on halving per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains.

The increase in awareness on FLW started with a few publications that raised the profile of FLW. The review of fragmentary evidence coupled with interviews with international food supply experts in Parfitt et al. (2010) was very influential in highlighting the scale of the problem, as was the FAO estimate that one third of food produced was either lost or wasted (FAO 2011). Concerning post-harvest losses (PHL), the World Bank (Zorya et al., 2011) highlighted the importance of PHL in cereals in Sub-Saharan Africa. On consumer waste, the Waste and

Resources Action Programme (WRAP) initiative in the United Kingdom led the way to demonstrate the magnitude of food waste in developed countries (WRAP, 2008, 2009). These publications raised awareness of FLW and its implications.

The extent of reported FLW raised concerns about food availability, farm and food supplier incomes, natural resource sustainability, food safety, and the global ramifications of their impacts. Even though those studies emphasized the need for more data, the idea that “one third of food produced is wasted” has stuck with many observers and policy-makers as a “stylized fact.”

With the increase in awareness came a call to action, such as the one by Lipinski et al. (2013), leading to adoption of a specific target for FLW reduction (SDG 12.3) as part of the Sustainable Development Goals (SDGs). This recognition was based in good part on the premise that reducing FLW would contribute substantially towards ending hunger and making consumption and production systems more sustainable. Such notions have subsequently been reconfirmed in influential studies on the sustainability of food systems (see e.g., the EAT Lancet report by Willett et al., 2019).

The spread of the novel coronavirus disease (COVID-19) in 2020 has drawn further attention to the risks of substantial food loss, particularly those of dairy, meats, fruits and vegetables, as social distancing measures have caused supply chain disruptions and demand to drop in many countries with a potential to increase losses specially in high value and nutrient-rich food commodities (Torero, 2020; Laborde et al., 2020). Both the pandemic and inadequate food access can increase morbidity

* Corresponding author.

E-mail address: andrea.cattaneo@fao.org (A. Cattaneo).

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Table 1

Five policy-makers needs on food loss and waste: what can be answered and what needs to be further developed.

Policy-relevant questions	What is known	What needs greater effort by practitioners
Q1 <i>Do we know how much food is lost or wasted?</i>	<ul style="list-style-type: none"> In the aggregate, a sizeable amount of food is being lost or wasted. Methodologies are being improved (FAO, 2019; FLW Protocol, 2016). However, it is difficult to harmonize approaches (Chaboud and Daviron, 2017; Ellison et al., 2019) 	<ul style="list-style-type: none"> Identifying critical loss points. Measurement approaches. Opportunities using blockchain.
Q2 <i>What are the causes of FLW?</i>	<ul style="list-style-type: none"> Food prices relative to production costs are critical explanatory variables in determining FLW rates. Economic incentives for adoption of FLW reducing technologies are weak. Deficiencies in public infrastructure. 	<ul style="list-style-type: none"> Better understanding of private benefits and costs as key determinants of FLW. Identifying indirect causes that need to be addressed as part of broader agri-food value chain development policies.
Q3 <i>What interventions are best suited to address FLW and how to target them? Should policymakers focus on loss, waste, or both?</i>	<ul style="list-style-type: none"> Depends on the underlying motivation of reduction (FAO, 2019). Even the appropriate measure (losses in tons, nutritional or economic value) depends on the objective (FLW Protocol, 2016). Strategies for reducing food losses and food waste will have to be different: for waste reduction consumer awareness is key; for loss reduction understanding private costs and benefits and what drives them is key. 	<ul style="list-style-type: none"> FLW reduction should be treated as an intermediate goal and interventions designed and targeted in function of the policy's ultimate goal (e.g. food security, reducing GHG emissions, etc.) Based on answers to Q1 and Q2, identify stakeholders for whom interventions can be most effective.
Q4 <i>What is the rationale for public intervention? How ambitious should we be in setting reduction targets?</i>	<ul style="list-style-type: none"> Overall economic welfare improves when lower FLW implies improved efficiency of food systems. Producing food that is lost or wasted has an environmental impact (Kummu et al., 2017). Food security and nutrition improves by reducing losses, as – in principle – more food becomes available at lower prices, benefiting households that are net buyers of food. Food banks that avoid food waste provide support to the food insecure. Achieving zero FLW may not be realistic, given increasing marginal cost of investing in FLW reduction (Ellison et al., 2019). 	<ul style="list-style-type: none"> Need to focus more on quantifying the actual environmental improvement obtained by specific interventions to reduce FLW once economic feedbacks of an intervention are taken into account. More research is needed on the distributional effects of FLW interventions: reducing losses could harm producers because of lower prices. Improving the assessment of efficiency, environmental and food security benefits of interventions, since there is very limited knowledge about societal benefits of reduction in FLW.
Q5 <i>Are there trade-offs and unintended consequences of reducing FLW?</i>	<ul style="list-style-type: none"> Impacts will be felt both upstream and downstream of an intervention. For example, reductions at one stage can trigger losses and waste elsewhere. FLW reduction leading to lower prices may affect incomes of food producers and weaken economic incentives to invest in FLW reduction. Efforts at improving food safety (reducing contaminants and spoilage) may cause higher reported FLW. 	<ul style="list-style-type: none"> Better understanding of how FLW reduction at one stage of the food value chain impacts market conditions upstream and downstream the supply chain. Identify trade-offs between different objectives associated with FLW reduction.

(FAO et al., 2020). At the time of writing, it was unclear whether these immediate impacts would have lasting effects on supply chains and consumption behavior, but no doubt they raise the importance of addressing FLW as part of the food policy agenda.

Since 2010, there has been a proliferation of empirical studies on FLW. According to Xue et al. (2017), two-thirds of the studies on the topic were published after 2010. Before 2010, the bulk of the literature on FLW was mostly technical in nature and confined to specialized publications and very few contributed to the economic literature. Despite the recent surge in policy-oriented studies, evidence to inform policymakers on the magnitude, causes and remedies of FLW remains extraordinarily sparse and highly diverse in methods, coverage of the stages of the value chain, and definitions. However, a number of recent studies signal the beginning of a new literature that can provide the basis for improved measurement of FLW and insights into the design of effective interventions. Some are conceptual (Bellemare et al., 2017; Koester, 2017; Ellison et al., 2019). Others are based on meta studies or literature surveys (Affognon et al., 2015; Sheahan and Barrett, 2017; Xue et al., 2017; Aragie et al., 2018; Reynolds et al., 2019). A few recent studies have emerged that have proposed and applied improved measurement methodologies (Garrone et al., 2014; Delgado et al., 2017; FAO, 2019) and have influenced the development of new protocols for accounting and reporting standards for FLW to be deployed by companies, governments, and other actors (FLW protocol, 2016).

The editors of this special issue (SI) on FLW believe there is a need to bring together the issues of measurement, methodologies, determinants of FLW, and trade-offs linked to policies or actions for reducing FLW. Effective policies and actions will require FLW to be adequately measured and their drivers understood. This paper, which serves as an

introduction to this special issue, summarizes what policy-relevant advances are needed. It outlines the contributions of the papers included in the special issue in these priority areas. A common denominator of these papers is the notion that FLW is largely driven by economic decision-making and behaviors of actors along food supply chains, from farmers to consumers. Policymakers aiming to reduce FLW will likely see their efforts fail if they do not properly account for these factors.

2. Meeting five policymakers' needs: Evidence from this special issue and remaining knowledge gaps

To address FLW, policymakers need to consider complex pieces of evidence. We group those information needs into five categories: (i) detailed measurement of the extent of FLW along food supply chains; (ii) evidence about the context-specific drivers of FLW; (iii) private and social cost-benefit assessments to identify potential effectiveness of interventions for reducing FLW and how to target those interventions; (iv) value chain or food system-wide assessments that help inform whether to specifically target FLW or make it a subsidiary goal of broader policies aiming at improving the efficiency and sustainability of food systems at large; and (v) identification of possible unintended and undesired implications of reducing FLW.

Table 1 summarizes these needs for evidence-based policy decision-making and identifies the main knowledge gaps in these five areas of interest to policymakers. Below, we provide an overview of the contributions made in this volume to each of the five categories of information needs. At the same time, the related challenges may serve as an organizing framework for a policy research agenda on FLW reduction.

2.1. Measurement

Since the first global assessment attempted by [FAO \(2011\)](#), progress has been made on both conceptual and measurement frameworks for FLW. As a result, the boundaries of FLW have been more clearly defined, the evidence base has increased, and global estimates of the magnitude of FLW have been refined. For example, [Xue et al. \(2017\)](#) were able to provide quantitative FLW estimates at the global level by major commodity groups. Using different sectoral boundaries and a mix of officially reported and model-generated data, [FAO \(2019\)](#) estimated food losses to amount to about 14 percent of food production at global level, considering losses occurring at the farm level as well as during storage, transport, processing and distribution of food. The new estimate does not include the amounts of waste occurring during the stages of retail and final consumption.¹

Fabi et al. (in this SI) start with an overview of the main conceptual frameworks proposed for measurement of FLW, followed by a meta-analysis of existing quantitative evidence on food losses and how it varies by product and region. For example, they find that median share of lost output of fruits and vegetables is more than 10 percent in Africa and Latin America, while in Europe and North America this share ranges between 4 percent and 7 percent. Losses in cereal production are lower across all regions – between 0.1 percent and 3.8 percent – and the difference between regions is less pronounced than it is for fruits and vegetables. In particular, the paper focuses on ways to improve monitoring progress towards SDG target 12.3. It makes clear that SDG target 12.3 can catalyze action, but also that the data challenges to overcome are considerable.²

Delgado et al. (in this SI) take an innovative approach to the measurement of food losses along the value chain of five staple crops in six developing countries allowing for the identification of critical loss points along the value chain. They test and compare four methodologies to account for both quantitative and quality losses from pre-harvest to post-harvest handling, processing, and distribution. They find that losses are highest at the farm level and most product deterioration occurs before harvest. Aggregated self-reported measures, which are most frequently used in the literature, consistently underestimate actual food losses.

Another dimension of imperfect measurement is linked to qualitative losses and how they are related to issues of food safety. Hoffmann et al. (in this SI) highlight how degraded quality may reflect a problem of food safety, but as in the case of aflatoxin in maize, food safety losses are not always readily observable by market actors. When this is the case, farmers, traders, and processors will lack incentives to address food safety losses specifically. If food quality is correlated with valued and observable food attributes, as Delgado et al. (in this SI) observe for maize, beans, teff, potatoes, and wheat, then quality losses are reflected in lower prices, thereby partially correcting this information failure.

Despite this progress, reliable and systematic evidence on the total amount of losses and waste is still missing for a wide range of commodities and along the whole food supply chain. Various papers in this SI contribute new evidence on the magnitudes of FLW in a variety of contexts (see first column in [Table 2](#)). Wider application of the measurement approaches proposed in this SI, especially for high-value food commodities, will be essential. Doing so, on a systematic basis for all countries and the wide range of food items, will also require finding more cost-effective measurement approaches than current methods

¹ Revised global estimates of food waste for downstream stages of food supply chains are in the process of being developed by the UN Environmental Programme (UNEP) to create a global food waste index.

² As an example of the challenges faced, taking the median estimates reported in Fabi et al. provides a different picture from the most recent FAO estimates of food losses, which uses a mix of officially reported and model generated data. The global average of food losses reported by FAO, estimated at approximately 14 percent, is higher than the highest median in Fabi et al.

based on surveys and model-based estimations. Blockchain technology and other tools for tracking produce along the supply chain could provide a basis for improved measurement.

2.2. Direct and indirect determinants of food loss and waste

Causes of FLW differ widely along the food supply chain and may be directly or indirectly linked to a specific loss point. Causes are context-specific. For example, we know that important causes of on-farm losses include inadequate harvesting time, climatic conditions, practices applied at harvest and handling, challenges in marketing produce, and lack of economic incentives to prevent losses (Delgado et al. - in this SI and [FAO, 2019](#)). Inadequate storage conditions and decisions made at earlier stages of the supply chain can predispose products to a shorter shelf life, causing significant losses ([FAO, 2011](#); [Liu, 2014](#)). Adequate cold or dry storage, in particular, tend to be crucial to prevent quantitative and qualitative food losses ([Delgado et al., 2017](#)). During transportation, good physical infrastructure and efficient trade logistics are vital to prevent food losses ([Rolle, 2006](#)). Confirming this, Minten et al. (in this SI) find that well-integrated rural–urban value chains have lower losses than typically found in the literature. Analyzing self-reported post-harvest loss from different value chain agents, they find aggregate post-harvest losses (PHL) over all segments of the value chain (from farmer to retailer) for teff and milk in Ethiopia, which amount to between 2.2 percent and 4.3 percent of total quantities produced.

Processing and packaging can play a role in preserving foods, but losses in these stages of the supply chain can be caused by inadequate facilities, technical malfunctioning of equipment, or human error. Brander et al. (in this SI) apply a randomized control trial to examine the effect of use of hermetic storage bags for maize on seasonal food security in two districts in Tanzania. They find that the adoption of this low-cost technology resulted in a 38 percent decrease in the proportion of severely food insecure people during the lean season. Delgado et al. (in this SI) find the presence of pests, lack of rainfall, and lack of appropriate post-harvest technologies to be major factors behind the losses in the food value chains covered in their study.

Concerning indirect determinants of FLW, [Sheahan and Barrett \(2017\)](#) rightly emphasize the importance of economic incentives and understanding the microeconomic rationale for why post-harvest losses occur, and that this is often missing in the debate on FLW. Using farm-level data, [Anríquez et al. \(in this SI\)](#) compare marginal benefits and costs of loss reduction in wheat farming in Tunisia and in the tomato supply chain in Egypt. They find that market incentives to reduce losses are absent in the case of Tunisia and rather weak in Egypt. This result highlights that actors along the food value chain will weigh private benefits and costs of reducing losses to determine whether to intervene, and to what extent. As pointed out by [Sheahan and Barrett \(2017\)](#), given the likely increasing marginal cost of reducing losses the ‘optimal’ level of food loss will most likely be greater than zero.

At the retail level, direct causes of food waste are mostly associated with limited shelf life, the need for food products to meet aesthetic standards in terms of color, shape, and size, and variability in demand. Consumer waste is often caused by poor planning during food purchasing and meal preparation, excess buying (influenced by overly large portion sizes and packaging), confusion over labels (“best-before” and “use-by” dates) and improper food storage at home. New insights in this regard are provided by [Yu & Jaenicke \(in this SI\)](#), who conduct a natural experiment and observe that extending a food product’s sell-by date has clear benefits for consumers who purchase less milk, spending less, but end up consuming more of it.

Another fundamental challenge stems from shoppers becoming less price sensitive as incomes increase. This is likely to lead to an increase in food waste in currently low- and middle-income countries ([Lopez Barera & Hertel, in this SI](#)). Furthermore, because avoiding FLW typically requires additional labor and increases production costs, the opportunity cost of investing in FLW reduction will increase with income levels.

Table 2
How the articles in this SI contribute to answering our five policy-relevant questions.

Contributions	Measure/ definitions	Determinants	Entry point	Rationale for public intervention				Trade-offs and unintended consequences
				Economic Efficiency	Distributional issues & Food security	Nutrition/ Food safety	Environmental impacts	
(1) Fabi et al. (2020)	X		X					
(2) Delgado et al. (2020)	X	X	X					X
(3) Anriquez et al. (2020)	X	X	X	X				
(4) Minten et al. (2020)	X	X	X	X				
(5) Qi et al. (2020)	X	X	X	X				X
(6) De Gorter et al. (2020)		X	X	X	X			X
(7) Chaboud and Moustier (2020)	X	X	X	X	X			
(8) Hoffmann et al. (2020)	X	X	X			X		X
(9) Brander et al. (2020)	X	X	X		X			
(10) Min et al. (2020)	X	X	X			X		
(11) Yu and Jaenicke (2020)		X	X			X		X
(12) Cattaneo et al. (2020)			X	X			X	X
(13) Kuiper and Cui (2020)			X	X	X	X	X	X
(14) Lopez Barrera and Hertel (2020)		X	X	X	X		X	X

As a result, first-order policy objectives aiming to improve productivity and incomes will naturally work against second-order policy objectives, such as FLW reduction. This suggests that pure market-based policy instruments may not suffice to simultaneously achieve both types of objectives. Other instruments may be needed, such as those that influence socio-cultural norms and awareness about food waste.

Min et al. (in this SI) find income levels matter when it comes to consumer waste and how consumers respond to better information about diets. The authors find that where the level of community development is low, dietary knowledge may increase food waste by households. However, where it is high, better dietary knowledge will decrease food waste. Consequently, policies promoting nutrition knowledge on food waste and loss should take note of differences in levels of community development.

In a similar vein, Hoffmann et al. (in this SI) find that greater awareness about food safety with regard to contaminants, spoilage, and other food quality aspects may lead to an increase in reported FLW. The authors highlight the challenges consumers face in correctly identifying proxies for food safety concerns as opposed to qualitative losses. This reiterates a point made earlier, which is that problems of FLW cannot be addressed in isolation. Rather, they should be treated in conjunction with other policy objectives related to health, food security and nutrition, and the environment.

2.3. How to target interventions?

Policymakers typically face resource constraints, requiring them to prioritize among multiple policy needs and, in the context of food policy, among sub-sectors within food systems. Specifically targeting FLW will require having detailed measurements of losses and waste by food product in the supply chain where they occur. This is needed to identify critical loss points by type of foods to be targeted and to quantify the costs and benefits of FLW reduction to justify targeted resource allocations.

For instance, the levels of food loss are generally much higher for

fruits and vegetables than for cereals and pulses (FAO, 2019; Fabi et al. in this SI). Studies on waste at the consumer stage, mostly confined to high-income countries, also indicate that waste levels are particularly high for foods that are highly perishable, such as animal products and fruits and vegetables (Lipinski et al., 2013; FAO, 2019).

Another challenge is deciding which actors to target when trying to reduce FLW, which can be fairly context specific. For example, Minten et al. (in this SI) find that, based on primary data from urban food retailers, the emerging modern retail sector in Ethiopia on average has only half the level of PHL incurred by the traditional retail sector. This could justify targeting interventions towards actors in the traditional retail sector. However, the finding may not be generalizable. Chaboud & Moustier (in this SI), for instance, do not find that losses are lower in modern marketing channels as compared with traditional ones in the case of Colombia's tomato value chains.

How best to focus FLW interventions will depend further on the policy objective. In the case of environmental objectives, Cattaneo et al. (in this SI) distinguish between pressure on natural resources (land and water use) and GHG emissions as the objective, and how this determines whether interventions should focus more on losses or on waste. De Gorter et al. (in this SI) show empirically that losses occurring in one stage of the supply chain can have cascading effects throughout the food chain. Policies should account for such effects when targeting interventions at any particular stage (primary production, distribution, processing, retail, or final consumption).

As mentioned, Delgado et al. (in this SI) account for losses along the supply chain for a range of staple crops in developing countries to find that losses are highest at the farm level and that most product deterioration occurs before harvest. This suggests that interventions at the farm level would be an important entry point, but the authors further point out that the reasons why farmers leave produce on the field or do not invest in better handling practices also depend on factors beyond the farmgate, such as lack of adequate storage capacity and market volatility (e.g., when output prices drop below the cost of hiring labor during harvest and other input costs).

Taking a global economy-wide perspective, Kuiper & Cui (in this SI) examine the role of loss reduction in different regions and for different commodities, while Lopez Barrera & Hertel (in this SI) look at the role of waste reduction in the coming decades. Kuiper & Cui make the case for targeting interventions by value chain in accordance with the primary objective of FLW reduction. They argue that for improving food security, reducing FLW in value chains for fruits and vegetables has highest potential, while for reducing GHG emissions larger impacts may be achieved through reducing FLW of animal products. Lopez Barrera & Hertel's projections to 2050 point to the need to prioritize policy interventions and behavior changes for waste reduction in middle-income countries, where uneaten calories per capita at the household level are expected to grow most rapidly.

2.4. The rationale for public intervention: Partial versus holistic approaches

Policymakers will have to decide whether FLW reduction is a first- or second-order policy objective. Put differently, should interventions specifically target the prevention and reduction of FLW or rather achieve this as part of broader interventions making food supply chains sustainable while improving food safety and food security and nutrition?

The reduction of FLW potentially may simultaneously improve food system efficiency and serve societal goals of food security and environmental sustainability. If FLW is caused by a lack of infrastructure (e.g., poor-quality roads) or public services (e.g., an erratic electricity supply), FLW can be viewed simply as a sector- or economy-wide efficiency loss. This would provide additional justification for the provision of public goods in the form of better infrastructure and basic services as part of a broader development strategy with FLW reduction as a second-order objective. Such interventions would improve the enabling environment, and market actors would be encouraged to invest in FLW reduction. Minten et al. (in this SI) and Chaboud & Moustier (in this SI) provide examples in Ethiopia and Colombia, respectively, of how well-integrated rural–urban agri-food value chains are the key to low losses.

Other market failures resulting in FLW also warrant complementary public intervention. For example, poorly functioning credit markets could deprive many farmers of access to finance to pay for the initial cost of adopting loss-reducing production systems. Public policies addressing such market failures can be essential for food supply actors to see an economic payoff of investing in FLW reduction. This is especially important when the business case for making such investments seems weak to individual stakeholders or when they do not have full information about the options available to them (see, for example, Anríquez et al. in this SI). Even where the business case for food loss or waste reduction is clear, stakeholders may be unable to implement the necessary actions because of financial constraints.

Pursuing FLW reduction as part of a social objective function requires looking beyond the individual business case. As mentioned, FLW reduction may be viewed as instrumental in improving food availability and access for the food insecure (FAO, 2019; Brander et al. and Kuiper & Cui, both in this SI). At the same time, reductions of FLW may be viewed as a way to lessen pressure on land and water resources, and reduce GHG emissions from agricultural production (Cattaneo et al.; Kuiper & Cui; Lopez Barrera & Hertel in this SI). The potential for such societal benefits would guide policymakers in the allocation of public resources for investments in FLW reduction. However, few of such social benefit-cost assessments related to FLW reduction are available and also difficult to undertake in practice.

Finally, nutritional and food safety considerations related to FLW may form additional reasons for public intervention. Regulation for food safety, such as requiring “conservative” labelling of sell-by dates that are very risk-averse, could increase the probability of food waste (see Yu & Jaenicke in this SI for the case of milk). Hoffmann et al. (in this SI) discuss the challenges informing measures to guarantee food safety based on evidence on qualitative food losses. The authors study the issue

by linking proxy indicators for food safety problems in the case of aflatoxin contamination to consumer perceptions about qualitative losses. Similarly, Min et al. (in this SI) provide evidence suggesting that improving dietary knowledge can be critical to behavioral change leading to food waste reduction and lower calorie loss at the household level.

2.5. Addressing trade-offs and avoiding unintended consequences

Lastly, a further critical issue relates to policy coherence. Coordination across policy domains will be required to address trade-offs between objectives, which in turn requires that all policy options are weighed together for their impact to arrive at solutions that promote one objective without unintentionally harming another one. De Gorter et al. (in this SI) stress the potential trade-offs between reducing natural resource stress, increasing farm welfare, and improving food security. Similarly, Cattaneo et al. (in this SI) point out that reducing losses may help improve supply-chain efficiency and food security but could induce greater GHG emissions from the food system (e.g., through greater energy use in cold chains as more food reaches the retail stage). Kuiper & Cui (in this SI) note, for example, that reducing food losses leads to an “expansion effect,” which could stimulate other economic activities and this rebound effect could induce more, not less, economy-wide GHG emissions on balance.

Other tradeoffs can arise if food policies to improve food security and nutrition have the unintended effect of increasing FLW. For instance, this could occur when these policies promote dietary diversity through greater production of nutrition-rich but also highly perishable foods, such as fresh dairy products, fruits and vegetables (see the cited example earlier of milk in Yu & Jaenicke in this SI).

FLW may occur as an unintended consequence of an inefficient and distorted food system. For instance, agricultural subsidies could lower food prices thereby weakening incentives for consumers and producers to avoid loss and waste of food. This may thus limit the effectiveness of more targeted interventions for FLW reduction, thus underlining the importance of policy coherence across food policy domains.

Economic development, independently of market distortions, can have an impact on levels of FLW. Lopez Barrera & Hertel (in this SI) indicate that the share of food waste tends to increase with higher per capita income, which could be seen as an unintended outcome of a successful development strategy. Unintended by-effects can also be positive. Another example of such impacts is provided by Qi et al. (in this SI) who find that with the liberalization of livestock markets and central policies promoting livestock intensification in China, the pressure for greater efficiency also induced lower waste of livestock products at the household level.

The choice of measurement concepts can also have unintended consequences. For example, as Delgado et al. (in this SI) point out, pre-harvest and harvest losses can be important, but tend to be left out as many measures focus only on post-harvest losses. Not considering the losses occurring before and during harvest may thus miss out on an important part of the problem. Failing to account for all losses along the supply chain could thus lead to overestimation of the impact of interventions.

3. Five policy challenges

Despite the proliferation of studies on FLW over the past decade, policymakers continue to face a dearth of information to guide policy-making, as identified in the five gaps illustrated earlier. The evidence provided in this special issue suggest five major policy challenges to achieving SDG target 12.3 of halving food waste and reducing food loss.

3.1. Challenge #1 - measuring and monitoring FLW is hard

The measurement challenges posed by FLW are epitomized by the

debate on the definition of what should be considered FLW. There is no single best definition. Definitions will be guided in part by what motivates the interest in FLW. For example, if stakeholders strive for a “circular economy,” they will probably only consider the food that is incinerated or ends up in landfills as lost or wasted. If food security is the main focus, all food that is not used for human consumption will be considered as waste, thus also including that used as animal feed. Therefore, the policy purpose will influence choices of concepts and units of measurement (FLW Protocol, 2016, Appendix D).

The recently developed Food Loss Index (FLI) measures the economic value of food losses, using farmgate prices of commodities (FAO, 2019). The index provides a common definition and is useful for cost-benefit assessments of interventions for FLW reduction. Alternative measures express FLW in terms of calories lost, which would be relevant for interventions focused on improving nutritional outcomes. If the policy focus is on environmental sustainability (e.g., reducing greenhouse gas emissions), it will be important to also measure FLW in physical quantities and relate these to the natural resource use and emission intensity of the related production processes.

The FLW Protocol (2016) recognizes this challenge and provides a framework that allows stating the scope of an inventory by choosing the material type being considered (food and/or inedible parts), what destination is considered FLW (animal feed, composting, bio-based materials, etc.), and the boundaries of the inventory (food category, lifecycle stage, geography, and organization). This approach brings clarity on the underlying assumptions of an inventory done using the FLW Protocol. A major challenge for policymakers is that the information provided under this system tends to be fragmented and rarely comparable across inventories.

Policymakers wanting to monitor progress towards the achievement of SDG 12.3 will need a consistent way of making inventories at the national level. While not in conflict with the FLW Protocol, it does require a transparent set of assumptions and methods to make sure the inventory properly reflects the FLW situation nationwide. The Food Loss Index developed by FAO (2019) and the Food Waste Index under development by UNEP are the agreed indicators to monitor SDG target 12.3. Progress is being made in this area. However, considerable data challenges in developing these indices remain. For now, much of the new evidence generation will continue having to rely on the ingenuity of researchers as highlighted by the effort of Lopez Barrera & Hertel (in this SI), who develop a new panel database on household food waste at the national level based on the Energy Balance equation, including adjustments for changes in body weight over time. Even so, these efforts cannot replace more detailed commodity-specific food waste estimates needed for more detailed commodity market modelling of global food systems.

The growing interest in using blockchain for traceability along food supply chains — intended to manage supply chain risks, prevent or respond to food contamination, disease, or pesticide residues — may become an important tool to address the challenge of measuring food losses in a commodity-specific manner and in real time (see Tripoli and Schmidhuber, 2018; Antonucci et al., 2019). For example, the United Nations Economic Commission for Europe is already piloting an online blockchain-supported marketplace for food that would otherwise be lost along the supply chain.

3.2. Challenge #2 – Assessing social and private benefits and costs of FLW reduction and the trade-offs involved requires significant analytical capacity and data

Weighing the costs and benefits of FLW reduction should provide essential policy guidance. Decisions of policymakers may be driven predominantly by social benefit-cost ratios, i.e., the current and future societal benefits as compared with a program’s expenditure or the cost of implementing a new regulation. Private actors (farmers, intermediaries, agro processors, wholesale markets, retailers and

consumers) will more likely assess whether their own economic gains of reducing FLW exceed the direct and opportunity cost of the related actions. Both need to be taken into account.

Actions to reduce food loss or waste may require the involvement of different actors, according to the type of food loss or waste targeted. A challenge can be that those needing to bear the costs of food loss or waste reduction are not necessarily the ones who enjoy its benefits. Indeed, the impact of FLW reduction efforts on farmers, processors, distributors, retailers, and consumers depends on how the effect on prices is transmitted throughout the food supply chain (De Gorter et al.; Cattaneo et al., in this SI). Some may benefit, while others may lose out. This is the case of extending sell-by dates whereby less milk is purchased, potentially causing a loss to producers, but more milk is consumed benefiting consumers (Yu & Jaenicke, in this SI).

The environmental dimension of benefits is also difficult to assess. For example, Kuiper & Cui (in this SI) find GHG emissions increase when food losses in animal products are reduced in primary production within a single region, but this increase could be nullified if reductions in primary animal production losses happen concurrently across all regions. The net effect depends on the relative emission intensities of food production in different regions, on trade, and general equilibrium effects outside the food sector. This type of environmental outcome is thus in part beyond the control of national policymakers. The domestic dimension of potential increases in GHG emission when food losses are reduced is confirmed by Cattaneo et al. (in this SI). They provide an assessment of the benefit of FLW reduction in three environmental dimensions (GHG emission, land use, and water use). They find that reducing food waste always reduces environmental pressures, and that reducing food losses can lead to an increase in GHG emissions from domestic production, negating the environmental grounds for interventions. The authors make the point that the environmental impact is always mediated through prices, making it difficult to measure the actual environmental benefit after economic adjustments to the intervention have taken place. Also, for other objectives, such as improvements in food security, it may be difficult to assign a monetary value to the benefits. For example, Brander et al. (in this SI) find food security benefits but fall short of doing a cost-benefit analysis, and these non-monetary assessments may well be the best information that can be made available to policymakers to inform their decisions.

Using a global partial equilibrium model projecting scenarios through 2050, Lopez Barrera & Hertel (in this SI) confirm that reducing food waste can contribute substantially to reducing pressure on land resources as well as improving food security and nutrition in Sub-Saharan Africa. They note, however, that associated benefits depend crucially on whether international markets are integrated or segmented.

De Gorter et al. (in this SI) highlight the potential conflicts between different policy goals, such as a reduction in resource stress, increases in farm welfare, and enhanced food security. The authors show that whether these outcome measures move together depends in large part on the domestic demand elasticity in combination with the prevailing trade regime. In addition, the authors emphasize that it is not clear that cuts in waste at the consumer level are always more beneficial than equivalent cuts at the producer level. The relative effectiveness of cuts, taking into account costs and benefits, will depend on the presence and magnitude of cascading effects, the relative costs of cutting waste rates at the two stages, and the distribution of waste rates along the supply chain.

3.3. Challenge #3 – Designing policies and interventions with limited information

As long as data remain scarce, scattered, of unknown quality or limited representation for specific policy needs, policymakers should spearhead context-specific studies of individual supply chains to inform targeted interventions to reduce FLW. However, conducting many such studies will take time and will be costly. This means that in the

immediate future, policies to change producer and consumer behavior will need to be identified with limited information. This limits decision-making as to how and where to target interventions to reduce FLW. Part of the solution would be to better integrate value chains for reducing food loss (rather than targeting food loss reduction directly) and putting incentives to induce food waste reduction at retail, food service and consumer ends.

Fabi et al. (in this SI) highlight the large variability in loss estimates and provide a roadmap for measuring food loss and monitoring it over time. However, this is but work in progress and will have to be supplemented by survey data at the country level, which are yet to be collected on a systematic basis. In general, considerable heterogeneity exists in food losses along value chains, suggesting that policies aiming to curb PHL in developing countries need to be informed by context-specific evidence and that solutions should not be generalized.

Another dimension that policymakers may find challenging is balancing issues of food safety and FLW, as exemplified by the results of Yu & Jaenicke (in this SI) on sell-by dates for milk, and Hoffmann et al. (in this SI) examining the interplay between observability of qualitative losses and food safety concerns for maize. The two papers highlight the difficulty of identifying an optimal level of loss or waste. In the case of milk, the sell-by-date is interpreted by consumers as a spoilage date leading to more waste than would be optimal, and the authors find that extending sell-by-dates results in waste reduction. In the case of maize, the limited observability of aflatoxin contamination can lead to unsafe food being consumed, thereby improving observability of contamination would lead to the removal from the supply chain of the unsafe food and as a result greater food losses will be reported. These two examples show how limited information can lead to FLW being above or below what would be optimal level if the missing information were available.

Finally, the impact of interventions will be often difficult to quantify. One example is provided by Cattaneo et al. (in this SI). The authors highlight that environmental impact of reducing FLW on water scarcity or land pressure will be difficult to evaluate because of heterogeneity of environmental impacts spatially (horizontal heterogeneity) and supply chains with diversified sourcing (vertical heterogeneity). As Min et al. (in this SI) show, heterogeneity among stakeholders also plays a role in terms of how dietary knowledge affects waste among consumers.

On a positive note, Minten et al. (in this SI) find that well-integrated rural–urban value chains have lower losses than typically found in the literature, indicating that it may not be necessary to invest in PHL reductions in well-integrated rural–urban value chains, allowing policymakers to focus PHL reduction efforts elsewhere, thereby easing the information requirements for policy design.

3.4. Challenge #4 – Interactions between stages along food value chain and across countries are not adequately understood in FLW reduction

When some food suppliers manage to reduce losses, this does not imply that there will be a net FLW reduction overall. Second-order market interactions (e.g., reduction in food prices) could cause rebound effects pushing FLW back up elsewhere in the system. The net effect will depend, among other things, on the degree of price adjustment determined by the price elasticity of supply and demand, and on how price effects are transmitted vertically from one stage of the food supply chain to the next, and horizontally across countries. FLW reduction could thus make food cheaper, which in turn could weaken incentives for consumers to avoid food waste, as much as it may increase the demand for food.

The interactions between stages along the food value chain are well captured by several papers in this SI. As mentioned, De Gorter et al. (in this SI) disentangle the cascading effects up and down the supply chain and find that interventions to reduce food waste are reinforced at subsequent stages in some cases, while the effects are offset in other cases. This underlines the importance of assessing FLW along the entire supply chain. Cattaneo et al. (in this SI) come to similar conclusions when

looking at environmental impacts. The authors find that price transmission along the supply chain plays a key role in determining environmental outcomes of FLW reduction strategies, highlighting that market structure will affect how FLW reduction strategies perform.

Using a global partial equilibrium model Lopez Barrera & Hertel (in this SI) find that segmented markets limit the impact of food waste reduction on both food security and environmental outcomes. Looking at losses along the supply chain, Kuiper & Cui (in this SI), based on a global computable general equilibrium model, find a modest global response in terms of aggregate primary production. This results from the net effect of an output-augmenting effect of reductions in on-farm losses dominating the contracting effects due to input-saving productivity improvements in processing. Furthermore, they find that while reductions in food losses may help reduce global GHG emissions emitted from agriculture, it may be offset by consequent increase in GHG emissions because of increased activity in non-food sectors. This indicates that food loss reductions may have limited impact on GHG emissions if not accompanied by emission reductions in other sectors.

3.5. Challenge #5 – Staying ahead of the game: Income transitions and the shifting importance of losses and waste

Although knowledge of waste levels in low-income countries is limited, it is generally considered that losses are proportionately larger in these countries, and that they decrease as per capita income increases. This is in line with the finding of Minten et al. (in this SI) that well-integrated rural–urban value chains tend to have lower losses, and as countries develop, rural–urban value chains will become more integrated and the share of losses will decrease. However, it is expected that the levels of waste will tend to increase with income as food expenditures become a smaller share of income. Furthermore, as the opportunity cost of time grows with incomes, the effort in waste reduction may decrease as time is put to more “productive” uses. These issues are well captured by Lopez Barrera & Hertel (in this SI) showing projections for increase in consumer waste. In 2050, in rich countries the share of food waste is anticipated to level off, so that middle-income countries, particularly China, and lower-income countries in South Asia, South East Asia, and Sub-Saharan Africa are expected to be largely responsible for global food waste.

Another aspect linked to rising incomes emerges from the contribution of Chaboud & Moustier (in this SI). They show that modern marketing channels do not necessarily generate fewer losses than traditional channels. This is because the demand for food by low-income groups, purchased through traditional channels, may reflect greater acceptance of lower quality produce than what more affluent buyers would purchase in modern markets. As incomes increase, this direct demand for low quality produce may disappear and would need to be replaced by a system whereby these products are redirected towards processing.

Min et al. (in this SI) highlight how food waste will continue to increase, with further economic development and urbanization in China in the future. However, improving the nutrition knowledge of food decision makers in China can help reduce food waste overall. They find that beyond a certain level of development, improved dietary knowledge will help reduce both food waste and calorie loss. As such, promoting dietary knowledge of food decision makers is expected to play an important role in reducing food waste and calorie loss.

Cattaneo et al. (in this SI) analyze the extent to which reductions in FLW can improve resource use efficiency in light of the increase in demand that will occur in the coming decades. In a forward-looking perspective, they suggest that land and water use efficiency improvements of reducing either food loss or food waste can lessen the impact of an increase in demand. Specifically, reducing waste can effectively counterbalance the shift in demand if the food waste avoided is equal to the increase in demand, thereby limiting GHG emissions. Counterbalancing demand growth through a corresponding waste reduction can serve as a rule of thumb in countries where food demand is expected to

increase. In countries with rising incomes the waste rate is expected to increase, and it will be difficult to reverse the trend.

4. Conclusions

The papers in this SI are grounded on two premises: (i) rational actors will undertake efforts towards FLW reduction insofar as the benefits of those efforts outweigh the costs for them; and (ii) this notion should be taken into account when designing policies for FLW reduction. The implication is that FLW policies demand vast knowledge of synergies, trade-offs, and potential unintended consequences. In general, a certain level of food loss or waste is unavoidable, and determining the optimal level of FLW may require a considerable amount of information that is not readily available. Lack of information can lead to excessive rates of FLW, but it can also lead to rates of FLW that are too low. An example of the former is when actors underestimate how much food is lost thereby limiting their perception of benefits from reducing it. Conversely, the latter can happen if unsafe food is being unknowingly consumed, and society may be better off discarding it, thereby increasing reported losses. Limited information also makes it more challenging for policymakers to target interventions where they will be most effective and justified.

The case for public intervention can be made on the grounds of improving food security and nutrition, overall efficiency, and reducing the environmental impacts of food systems. The extent of these benefits may guide policymakers in determining how much public money to devote to this objective; however, the quantification and comparison of these effects may prove difficult in practice.

In this overview paper, we presented critical policy questions and assessments of available evidence and knowledge gaps to identify five major challenges to policies aiming to reduce FLW. These questions and challenges span issues of measurement of FLW, of quantifying the benefits and costs, and examining the linkages between different parts of the value chain and trade-offs between food policy objectives. Inevitably, policy design will have to grapple with the heterogeneity in the degree of FLW along and across value chain and different contexts, as well as differences in interests of actors in the food system.

Despite the challenges, the papers in this SI provide additional guidance on how to improve measurement of losses to better target interventions and the type of interventions that can help reduce FLW. On the loss side, this means investing in policies that provide an enabling business environment, such as market access, improving storage options, and integrating rural–urban value chains. Governments can also work towards FLW reduction by raising suppliers' and consumers' awareness of the benefits (making the business case) of any reduction. They can play an important role by modifying incentives to reduce FLW (changing the business case). For example, by issuing regulations that affect the decisions of individual actors regarding FLW or providing financial incentives for reduction through taxes, subsidies, or exemptions. In some cases, fine-tuning these policies will require context-specific information on the value chain to focus on and identifying the point of intervention along the supply chain. However, such detail should not distract from the broader societal objectives of improving food-system efficiency, food security and nutrition, and environmental sustainability.

Disclaimer: The views expressed in this publication are those of the authors and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations (FAO), the Consultative Group on International Agricultural Research (CGIAR) or the International Food Policy Research Institute (IFPRI).

CRedit authorship contribution statement

Andrea Cattaneo: Writing - original draft. **Marco V. Sánchez:** Writing - review & editing. **Máximo Torero:** Writing - review & editing. **Rob Vos:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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