The EFFICIENT protocol

A pragmatic and integrated methodology for food loss and waste quantification, analysis of causes and intervention design

M.G. (Melanie) Kok MSc, dr. R.B. (Bob) Castelein, dr.ir. J. (Jan) Broeze and drs. ing. J.C.M.A. (Joost) Snels

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Institute: Wageningen Food & Biobased Research

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PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr.

Abbreviations

APHLIS	African Postharvest Losses Information System
CEC	Commission for Environmental Cooperation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FLI	Food Loss Index
FLW	Food Loss and Waste
FWI	Food Waste Index
GFLI	Global Food Loss Index
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeid
IFPRI	International Food Research Policy Institute
PHL	Post-Harvest Loss
RLAT	Rapid Loss Appraisal Tool
SCL	Supply Chain Link
SDG	Sustainable Development Goal
UNEP	United Nations Environmental Programme
WRAP	Waste and Resources Action Programme
WRI	World Resources Institute

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Preface

This report underpins the new food loss and waste (FLW) quantification methodology (labelled the EFFICIENT protocol for EFFectIve food Chain IntervENTion) developed by Wageningen Food & Biobased Research (WFBR) within the Consortium for Innovation in Post-Harvest Loss & Food Waste Reduction. The EFFICIENT protocol was developed with the aim of introducing an accessible, pragmatic, and solution-oriented methodology to quantify and address FLW, while also being robust enough to be generic, reliable and comparable to report and track progress towards Sustainable Development Goal (SDG) Target 12.3 – to reduce food losses in production and supply chains, and to halve per capita food waste by 2030. The EFFICIENT protocol provides this, improving users' understanding of (their part of) the food system, and shortening the time needed to have significant impact with the appropriate FLW-reducing interventions.

The reader should consider this paper as contextualization and elaboration of the EFFICIENT protocol and the development thereof. It first starts with a comparison of existing FLW quantification methodologies and identifies gaps among those methodologies that could be addressed within the EFFICIENT protocol. The second part details the underpinnings and workflow of the EFFICIENT protocol itself.

A reader interested in quantifying and addressing FLW in their own situation (whether this is a country, supply chain, organization, or a single process) can use the first section as a guide to selecting the appropriate quantification methodology for their context, question, resources, and requirements. If they find that the EFFICIENT protocol serves their needs the best, they can refer to the second part of this report for an in-depth look at the protocol. A reader interested in FLW quantification and mitigation in general may want to read the entire paper.

Summary

Worldwide one-third of the food is lost or wasted, and food loss and waste (FLW) is a threat to food security and a significant contributor to greenhouse gas (GHG) emissions. Therefore, the UN SDG Target 12.3 sets the aim to reduce food losses in production and supply chains and to halve food waste per capita by 2030 against the reference year 2015. The formulation of this goal has accelerated the development of numerous quantification methodologies to quantify FLW and monitor progress towards SDG Target 12.3. Moreover, several of these quantification methodologies allow users – government, NGO, and private sector alike – to identify loss hotspots, and – ideally – take action to address this. This proliferation of FLW quantification methodologies is a reflection of increased awareness of the issue. However, as each of the existing methodologies are developed for a specific aim and audience, it still it may be hard for food chain actors to find a quantification methodology that fully meets their needs. In this paper the authors select twelve quantification methodologies that meet the criteria of having a FLW quantification purpose, being generic enough for use by a variety of users for various purposes, being actually used in studies by others, and offering something significantly new in addition to existing methodologies. The paper provides an overview and comparison of these twelve quantification methodologies and discusses their workflow and suitability for different purposes. Despite the large offering of quantification methodologies, there is still a need for a pragmatic, robust, and intervention-oriented approach with careful and logical alignment between the Measuring, Targeting, and Action phases, that is easy to implement with limited resources for the purposes of a variety of stakeholders. The authors proceed to develop a new methodology that meets this need – the EFFICIENT protocol - based on design principles and criteria stemming from the gap identified.

1 Introduction

In 2010, Monier et al. (2010) published the amount of food wasted in the European Union (EU). The study estimated the annual food waste generated in the EU27 at approximately 89Mt in 2006. In 2011, during the world's first Save Food conference in Dusseldorf, Germany, the Food and Agriculture Organization of the United Nations (FAO) launched the global food losses and food waste report, stating that one-third of the available food is lost or wasted worldwide (Gustavsson et al. 2011). The results from this report have since become the reference on global food loss and waste (FLW) data. In 2013, the FAO published the food wastage footprint which emphasized the threat of FLW for food security and induced greenhouse gas (GHG) emissions (FAO 2013). These different publications were the starting point for the European Union (EU) to investigate the development of a harmonized approach on FLW quantification, against the backdrop of the EU policy to reduce food waste with 50% by 2025 (Resource Efficiency Flagship) (EU FUSIONS 2012-2016[1]). Also, individual EU countries, like the Netherlands, started to monitor their annual FLW on country level (Soethoudt and Timmermans 2013). In 2015, the EU launched its Circular Economy Action Package, including the food waste reduction target: 30% by 2025. At the UN Summit in September 2015, the 17 Sustainable Development Goals were adopted by world leaders, including Target 12.3 to "halve per capita global food waste at the retail and consumer levels by 2030 and reduce food losses along production and supply chains, including post-harvest losses". Although the SDGs are not legally binding, governments are expected to take ownership and establish national frameworks for the achievements of the goals. As countries have the primary responsibility for follow-up and review of the progress made in implementing the SDGs, the Target 12.3 expresses the need for quantifying FLW to know the progress regarding the reference year 2015.

"What gets measured gets managed. If one does not know how much or where food loss and waste is occurring, how can one be expected to do something about it" (Lipinski et al. 2013)

As a result of the different publications on the amount of FLW, and the launch of the SDG target 12.3, quantifying FLW received a lot of attention and the need for a harmonized FLW quantification methodology increased.

Joint efforts in working groups and research projects on FLW quantification and methodology standardization have arisen like the Global Initiative on Food Loss and Waste Reduction: Save food (FAO 2014), EU platform on Food Losses and Food Waste (2016), EU FUSIONS (2012-2016) and EU REFRESH (2015-2019). These collaborations issued a series of publications covering various aspects of FLW definition, quantification, and mitigation and valorization strategies (Östergren 2014; Stenmarck et al. 2016; Metcalfe 2019; Bos-Brouwers et al. 2020; Wunder et al. 2020). Also other collaborations between organizations, like the World Resource Institute (WRI), United Nations Environment Programme (UNEP) and FAO, resulted in new quantification methodologies to track progress towards SDG Target 12.3. For example in 2016, the Food Loss and Waste Accounting and Reporting Standard was published, that enables a wide range of entities – countries, companies and other organizations – to credibly, practically and consistently report how much FLW is created and to identify where it occurs (WRI, 2016).

[1] : https://www.eu-fusions.org/index.php/about-fusions Accessed 25-06-2021

In 2018 the FAO developed indicator 12.3.1.a – Food Loss Index (FLI), focusing on losses that occur from production up to the retail level, including production, handling and storage, and processing. The objective of this indicator is to show the impact of policy and investments on the efficiency of food supply chains and the food system. Currently the FLI System monitors the percentage of loss of ten major commodities by country (FAO 2018a). Indicator 12.3.1.b - Food Waste Index (FWI) was developed by UNEP and it presents the most comprehensive food waste data collection, generates a new estimate of global food waste, and recommends approaches for countries to measure food waste at household, food service and retail level, to track national progress towards 2030 and to report on SDG Target 12.3. (UNEP 2020). These ideas on the importance of monitoring and quantifying FLW are also found in the literature on Post-Harvest Loss (PHL) mitigation (Xue et a. 2017; Sheahan and Barrett 2017; Chauhan et al. 2021).

Despite these efforts on the quantification of FLW and the standardization of methodologies, data deficiency and inconsistency remain significant concerns, and existing global FLW data suffers from gaps and imbalanced coverage. First, the spatial coverage o is narrow. Most research is conducted in more industrialized countries like the UK, United States, and Sweden (Xue et al. 2017; Chauhan et al. (2021). Second, large numbers of studies focus on food waste at the retail and consumer levels, with a more limited body of research focusing on food loss along the food chain. Third, outdated data is still used as secondary data in ongoing research. Fourth, there is inadequate first-hand data being collected, and studies rely on data derived from literature (Xue et al. 2017). For example, studies have frequently quoted data reported by Gustavsson et al. (2011), which may not be accurate for some countries and commodities. Lastly, the different studies are difficult to compare, since the system boundaries, methods, and definitions of FLW used vary considerably between studies (Xue et al. 2017). In addition to issues with FLW data and monitoring, it is not always apparent how to take the step from monitoring to action against FLW. Sheahan and Barrett (2017) found that many FLW quantification methodologies focus on monitoring only and lack a clear perspective on specific and appropriate ways to reduce the amount of FLW. Research is motivated primarily by invocation of the estimated amount of PHL and not by what the amount means nor by its consequences or mitigation options (Sheahan and Barrett 2017).

The quantification methodologies that were developed during the past years provide guidance and requirements on what should be measured, how to measure, what unit of measurements to use, what data sources and quantification methods are appropriate, how to ensure comparability, and how to report (Stenmarck et al. 2016; WRI 2016) – with varying purposes, priorities and degrees of detail. Quantification methodologies can focus on quantifying FLW at national level (Tostivint et al. 2016; Delgado et al. 2017; FAO 2018a; UNEP 2020), focus on a wide range of entities active in multiple supply chain links (GIZ 2015a; Rockefeller Foundation 2016; WRAP 2018), or both (Hodges 2013; UNEP 2014; WRI 2016; FAO 2018b; CEC 2019). The aim, level of analysis, and structure of quantification methodologies matters significantly for the applicability in each situation, and likewise, the aim and situation of a user are major deciding factors in their choice of methodology. For example, for policy makers insight at the national level may be most appropriate, as this information fits the scope of their possibilities for intervention, whereas for individual organizations, an insight into the losses in their supply chain is most preferable. Other quantification methodologies focus on the analysis of multiple supply chain links or complete supply chains, from farm to consumer, for both companies and governments, but are more general and descriptive (CEC 2019; FAO 2018b).

Lastly, several quantification methodologies were developed focusing on the direct execution of measurements for one specific supply chain line or sub-sector (Soethoudt and Snels 2016; National Zero Waste Council 2018). Although this latter group can be helpful for specific cases, these are often not widely used and implemented.

Quantities of FLW are most often estimated based on literature reviews and existing statistical data (FAO 2014). Xue et al. (2017) found that only around 20% of the publications they reviewed (N=202), that reported FLW data, relied on direct measurements or approximations based on primary data collection. An underlying reason for the lack of primary data is their relatively time-consuming nature and high associated costs as compared to secondary data collection from existing statistical sources (Xue et al. 2017). Businesses, governments and other organizations can take steps towards reducing the amount of FLW by monitoring and quantifying FLW in their supply chains. However, against a business context with limited time and resources, a balance must be struck between reliability and level of detail of quantification on the one hand, and the business case for comprehensive primary data collection on the other hand. Moreover, when it comes to impact, any form of quantification is only instrumental to the ultimate aim of implementing the right intervention in order to reduce FLW. In such a setting, primary data collection is not conducted to collect more accurate data, but to know where and how to implement improvements of existing processes.

Through quantification, the FLW hotspots in the supply chains can be identified, which helps to understand where to make changes or where to invest to have the most impact on reduction of FLW (Kok and Snel 2019). After the hotspots and causes of food loss are known, the right intervention can be identified. Especially in developing countries, high initial costs, high use of energy and a lack of rewarding markets lead to failure in adoption of technologies (Affognon et al. 2015; Shafiee-Jood and Cai 2016). Therefore, the intervention that is to be implemented should fit the context of its food system (Van Berkum et al. 2018). It should be profitable on the long term, be good for the environment, give more access to food for the people that need it most, and be socially and culturally acceptable (FAO 2014). Currently, the overall magnitude and general causes of FLW in food supply chains are known, including the beneficial effect of FLW reduction (Chauhan et al. 2021). However, the allocation of amounts of waste to different causes, and the impact and feasibility of different solutions are still unknown (FAO 2014; Chauhan et al. 2021). This underlines the need for a quantification methodology that not only allows users to quantify the amount of FLW (measure), but also to identify the hotspots (target) and find tailor-made solutions (act) to reduce FLW.

The goal of this report is to categorize existing FLW quantification methodologies (along the criteria formulated by Xue et al. (2017)), outline the most important properties of their workflow, and discuss an example of a use case (user, aim, resources, and context) where the methodology would be appropriate. Examining different quantification methodologies alongside each other allows for a gap analysis to identify the type of users and purposes that are currently not yet served comprehensively by existing quantification methodologies. This leads us to propose an additional methodology, namely an intervention-oriented FLW quantification methodology that presents a complete Measure → Target → Act strategy, is less laborious and less costly, and therefore can be more easily adopted and more frequently implemented, while safeguarding reliability, genericity and comparability to be able to report and track progress towards SDG Target 12.3. This can be achieved by strategically using existing data and knowledge, and supplementing this with targeted additional primary data collection where necessary. Furthermore, the quantification methodology aims to better support the identification of FLW hotspots and their causes and helps prioritizing appropriate interventions to shorten the time to impact.

This paper starts with a classification of existing methodologies for measuring and addressing FLW, and assesses their usefulness for different purposes. Most importantly, we distinguish the following purposes of FLW monitoring:

- Policy making
- Knowledge development/research
- Improving existing supply chain practices

Subsequently, we identify the gaps within existing quantification methodologies, and elaborate the EFFICIENT protocol which aims to close them.

2 Background

Numerous organizations and institutes have developed FLW quantification methodologies to facilitate and standardize the quantification of FLW. However, the ultimate goal of quantifying FLW is not just to publish the right figures, but to stimulate commitment from actors and governments to actively try to reduce the amount of FLW to reach the SDG Target 12.3 to reduce food losses in production and supply chains and to halve food waste per capita by 2030 against the reference year 2015.
In this report, currently available FLW quantification methodologies are reviewed to identify their contribution, application contexts, and investigate whether users with all types of different needs and contexts are served with this current offering, or whether a new methodology can have added value.

Table 1 shows a list of FLW quantification methodologies found by using the search criteria 'food loss and waste measurement' and 'food loss and waste quantification' on Google, Google Scholar and Scopus, searching on different platform websites relevant for this topic (e.g. FAO, CEC, IFPRI), and a review of the empirical literature on FLW quantification. The criteria for inclusion of methodologies in this overview were that first, the methodology was developed specifically for quantifying FLW (or aspects thereof), secondly that it was developed to be generic enough for FLW quantification across supply chain links, sectors, and countries (e.g. specific national or case study methodologies were not included), third that we could find evidence of it being used in other FLW studies (i.e. methodologies that saw uptake beyond the publishing institution), and fourth that the methodology offered something new in addition to existing methodologies (i.e. not only referring to existing methodologies, but for example presenting a new aggregation or synthesis methodology).

We consider a quantification methodology as a coherent set of instructions for the quantification (collecting, measurement and/or reporting) of FLW. Some methodologies are part of a larger initiative (that would specify overarching strategies and objectives, to the achievement of which the methodology should contribute) or contain a more specified set of step-by-step instructions (sometimes with purpose-made templates or tools).

Table 1 Food loss and waste quantification methodologies

Organization	Name of methodology
CEC (2019)	Why and how to measure food loss and waste: A practical guide.
FAO (2018a)	Global Food Loss Index (GFLI).
FAO (2018b)	Guidelines on the measurement of harvest and post-harvest losses: Recommendations on the design of a harvest and post-harvest loss statistics system for food grains (cereals and pulses).
UNEP (2020)	Food Waste Index (FWI)
WRAP (2018)	Food waste measurement principles and resources guide.
IFPRI (Delgado et al. 2017)	The reality of food losses: A new measurement methodology.
EU FUSIONS (Tostivint et al. 2016)	FUSIONS Food Waste Quantification Manual to Monitor Food Waste Amounts and Progression.
WRI (2016)	Food loss and Waste Accounting and Reporting Standard.
GIZ (2015a)	Rapid Loss Appraisal Tool (RLAT) for agribusiness value chains: User guide for maize.
UNEP (2014)	Prevention and reduction of food and drink waste in businesses and households: Guidance for governments, local authorities, businesses and other organizations.
APHLIS (Hodges 2013)	African Postharvest Losses Information System (APHLIS) and How to assess postharvest cereal losses and their impact on grain supply: rapid weight loss estimation and the calculation of cumulative cereal losses with the support of APHLIS.
Rockefeller Foundation (2016)	Yieldwise Food Loss Initiative.

2.1 Assessing the methodologies

The existing quantification methodologies are analysed and characterized using five indicators from literature, presented and explained listwise below.

1) Strategy: a) The extent to which the quantification methodology covers the complete Measure → Target → Act strategy or parts thereof (Lipinski et al. 2017). This includes measuring or collecting data (Measure), finding food loss hotspots and causes (Target), and defining and implementing the right intervention(s) (Act).
2) Genericity: a) The applicability of the methodology for specific level of analysis b) the ability to make the results comparable regarding definition and data collection method.
3) Accessibility and laboriousness: Consisting of a) the ease of reading, implementation, and interpretation of the quantification methodology the first time you want to use it, b) availability of building blocks to build and adapt (a part of) your own measurement methodology, survey or questionnaire, c) the execution time of the developed tools, including performing the measurements, interviews or workshops, and d) guidance on data analysis.
4) Practical guidelines or description: a) The availability of supporting documentation, guides, interactive tools and/or templates to give users an easy start. This criterion relates to format, rather than content as criterion 3) above.
5) Reliability and validity: a) The extent to which the quantification methodology produces robust and reliable results. This includes the type of data collection methodology.

There are unavoidable trade-offs between these criteria that needs to be considered in the development process of such methodologies, and the trade-off struck is determined by the ambitions – and resulting methodology and emphasis – of the developer. Therefore, these criteria do not serve to assign scores and evaluate the quality of methodologies, but rather describe differences between them that a user must consider before deciding which quantification methodology is the best for them (rather than 'the best' overall, which is not a judgment that can be made considering the heterogeneity of methodologies). For example, a comprehensive Measure → Target → Act strategy is more laborious than a methodology comprising on only one of these steps, and also within measurement-only methodologies, a balance must be struck between time and cost of implementation on the one hand and the degree of detail, quality, and reliability of the measurement on the other. Another trade-off is balancing the usability and adaptability of the quantification methodology for specific users' contexts on the one hand, and comparability between different situations in which the methodology was implemented on the other. While flexibility and adaptability lower the barrier for implementation and shorten the time to intervene in the supply chain, it limits the extent to which different iterations of FLW quantification (sometimes even using the same methodology) build towards a shared knowledge base with comparable data. However, despite these necessary trade-offs, more alignment on definitions, methods, and system boundaries is desirable to ensure quality of implementation and reporting, and increase comparability between studies (Xue et al. 2017).

Section 3 below explains these criteria in more detail and reviews how the different quantification methodologies incorporate these criteria and balances the trade-offs involved, as well as a global overview of the workflow involved in these methodologies (i.e. sequences of steps) and an illustration of the types of cases for which specific methodologies are appropriate.

3 Review of existing quantification methodologies

3.1 Strategy

a) Measure → Target → Act strategy

A completely comprehensive quantification methodology would cover the steps from measurement, to targeting relevant hotspots, to facilitating action on the information with specific improvements – all in an integrated way. Depending on their specific purpose, the strategies of existing quantification methodologies differ considerably, some encompassing all steps of this strategy, whereas others focus on one or two specific steps (Table 2).

Table 2 Strategy summary

	Measure	Target	Act
CEC (2019)	x	x	x
WRAP (2018)	x	x	x
UNEP (2014)	x	x	x
GIZ (2015a)	x	x	x
Rockefeller Foundation* (2016)		x	x
APHLIS (Hodges 2013)	x	x	
FAO (2018b)	x	x	
EU FUSIONS (2016)	x	x	
FAO (2018a)	x	x	
UNEP (2020)	x	x	
WRI (2016)	x	x	
IFPRI (*Delgado et al.* 2017)	x		

*The 'Target' and 'Act' phase is included, but not well defined.

IFPRI (Delgado et al. 2017) primarily focuses on measuring. It includes some part of targeting, but only at a very high level, distinguishing only between the producer-, middleman- and processor stages of food supply chains. "Monitoring" comprises the first two steps in the Measure → Target → Act approach. Six of the quantification methodologies reviewed focus on the 'Measure' and 'Target' phases. Often these are purpose-made quantification methodologies that facilitate data collection in a comprehensive way that allows the user to identify relevant FLW hotspots. Through this type of monitoring, countries and companies can focus on a specific part in the supply chain or on their process. FAO (2018b) aims to present a cost-effective method for quantifying losses and focuses on the 'Measure' and 'Target' phases of the Measure → Target → Act strategy. Likewise, the Food Waste Index (UNEP 2020) focuses on measurement, but also outlines how, with sufficiently granular and high-quality data, food waste hotspots (in terms of chain stages, sectors, or products) can be identified, which can support targeted prevention strategies. Also APHLIS (Hodges 2013) focuses on the first two steps of the Measure → Target → Act strategy, since their goal is to collect, analyse and disseminate data on postharvest losses. WRI (2016), EU FUSIONS (Tostivint et al. 2016) and FAO (2018a) focus on monitoring FLW amounts in the supply chain. Both WRI (2016) and EU FUSIONS (Tostivint 2016) also describe how to report the results.

On the other hand, the methodology of the Rockefeller Foundation (2016) focuses only on the 'Target' and 'Act' steps in its 'Yieldwise' initiative. The aim of Rockefeller Foundation (2016) is to reduce FLW throughout a few selected value chains by focussing on four categories of interventions. The value chains and interventions were already targeted in the development of the initiative, and more specified in the different pilots. However, the methodology of how the supply chains and the interventions are selected is not explained thoroughly (Rockefeller Foundation 2016).

CEC (2019), WRAP (2018), UNEP (2014) and GIZ (2015a) do include the complete Measure → Target → Act strategy. However, they differ in the comprehensiveness of guidelines and the level at which they recommend action (e.g. high-level policies versus specific chain interventions). For taking action, CEC (2019) defines that every intervention requires a business case to be made before deciding to invest in a specific intervention, while WRAP (2018) refers to other sources to guide businesses through the process of taking action to reduce FLW. Also for UNEP (2014), suggested interventions are not targeted, but are rather broad-scope policies and campaigns. The Rapid Loss Appraisal Tool (RLAT) developed by GIZ (2015a) includes interventions as well, but the possibilities are defined through (and therefore limited by) a participatory research approach, since target supply chain stakeholders are expected to bring forward suggestions for improvements and implementation options. Although this participatory research setup limits the range of options considered, it does help to bring forward interventions that are context-appropriate, acceptable by stakeholders and fit within the food system.

To conclude, elements of the Measure → Target → Act approach are included in all reviewed quantification methodologies. They all incorporate some form of monitoring, although particularly limited for Rockefeller Foundation (2016) and IFPRI (Delgado et al. 2017). Five quantification methodologies include all three elements. However, they do not describe all three elements with the same level of detail, the level of analysis differs and the process of progressing through the Measure → Target → Act strategy differs. Overall, the recommended actions are high-level and not context specific. Only GIZ (2015a) does cover context specific interventions, but the interventions are limited due to the participatory research approach; only target supply chain stakeholders are expected to bring forward suggestions.

3.2 Genericity

a) Level of analysis

Regarding the genericity, the level of analysis and the ability to make the results comparable regarding definition and data collection method are taken into account (Table 3).

Table 3 Genericity summary

	Comparability → Yes	Comparability → No	Comparability → ?
Country level	EU FUSIONS (Tostivint et al. 2016) FAO 2018a IFPRI (Delgado et al. 2017) UNEP 2020		
Value chain (link) level	GIZ 2015a	WRAP 2018	Rockefeller Foundation 2016
Applicable for both	APHLIS (Hodges 2013)	WRI 2016 CEC 2019 FAO 2018b UNEP 2014	

Of the reviewed methodologies, four quantification methodologies focus on the quantification of FLW through the years on the country level only (Tostivint et al. 2016; FAO 2018a; UNEP 2020). IFPRI (Delgado et al. 2017) also wrote their quantification methodology mainly for higher-level policy, and distinguished just three stages in the supply chain; producers, middlemen and processors.

A second group of quantification methodologies focuses on the level of specific value chains or chain links, which can include companies, supply chains, food systems (broadly defined) and/or actors (Rockefeller Foundation 2016; WRAP 2018; GIZ 2015a). However, differences exist in how these methodologies guide decision-making. The Yieldwise Food Loss Initiative of Rockefeller Foundation (2016) offers solutions, including linking farmers to markets, helping farmers access technologies, investing in financing models and technology innovation, and engaging global businesses in accounting for the FLW in their supply chains. Rockefeller Foundation (2016) puts special focus on the collaboration between innovative companies and specific actors in the supply chain. However, interventions that are successfully introduced in one specific supply chain-country combination do not automatically work in other supply chains as well, reducing the genericity of the Rockefeller Foundation (2016) methodology. Different cultures, infrastructure, geography, and economic factors drive differences between food systems and constrain the suitability of interventions to the local context. The RLAT by GIZ (2015a) addresses this by incorporating a participatory research design with an important role for supply chain actors themselves.

The third group consists of quantification methodologies that can be used to both analyse specific (part of) value chain (links) and on country level (WRI 2016; CEC 2019; FAO 2018b; Hodges 2013; UNEP 2014),

b) Comparability

To be able to compare the results of different FLW quantification methodologies it is not sufficient to have the same target audience. Quantification methodologies that are applicable for different situations are generic and often easy to adapt to specific situations and requirements. As a drawback, this adaptability also makes it difficult to compare different studies implemented with the same methodology.

For example, the FLW Accounting and Reporting Standard from WRI (2016) gives users the choice to decide what data gathering methodology to use and how to define the scope of the research. The last includes defining the materials that are included in the inventory (food only, inedible parts only, or both), and defining FLW in terms of the destinations where side streams go when removed from the food supply chain (WRI 2016). CEC (2019) and WRAP (2018) follow the Food Loss and Waste Accounting and Reporting Standard from WRI (2016) in their scoping recommendations. The guidance of UNEP (2014) emphasizes that the methodology should be tailored to fit the context and stakeholder objectives. This makes the guidance adaptable, but therefore studies that use the same guidance are not always comparable, unless different actors implement the guidance in the exact same way. Although the methodology described by FAO (2018b) intends to enhance the strengthening and harmonization of data collection, it proposes different food loss assessment tools, like sample surveys, field trials, regression modelling, or a combination of these – for the user to select the tools that fit their question and context best. The result is that different users will select different data collection methodologies and therefore the results are more difficult to compare.

Quantification methodologies may be developed for use in one context, but set up in such a way that they can be generally applied. For example, the methodology described by EU FUSIONS (Tostivint et al. 2016) focuses on coherent methods to acquire national data, making it possible to compare the results between member states more easily. This methodology forms the basis of current European guidance on FLW measurement, but it can also be used by countries outside the EU when they want to use the definitions as described by the EU. Also, the FLI (FAO 2018a) describes formulas, definitions, and guidelines so that it is possible to compare food losses from different countries. However, it must be considered that it is possible that countries only select the index top ten commodities specified by FAO as the default selection, yielding a rather narrow view on FLW. Targeting specific products and comparing the results between different countries is therefore limited. The related FWI (UNEP 2020) has a similar scope, being based on food waste statistics at the country level (ideally collected in line with the authors' recommendations) to facilitate a global comparison. GIZ (2015a) uses ten process steps that are generic and applicable to any value chain. This makes it possible to compare different studies, since they all use the same method, that consists of a desktop study, key expert roundtable, stakeholder workshop, focus group and processor meetings and a key informant meeting – all using provided templates with a given structure. The authors of the quantification methodology of IFPRI (Delgado et al. 2017) used a standardized survey, ensuring a consistent method across commodities and regions. So in case the respondent sample is of sufficient size, the results are comparable (Delgado et al. (2017) included approximately 1200 respondents per country studied), APHLIS (Hodges 2013) is a methodology that provides estimates on postharvest losses. The data APHLIS used is always based on two principles: literature and contextual factors. Own data can also be used in combination with the downloadable loss calculator.

To conclude, quantification methodologies that ensure that studies are comparable are in nine out of twelve methodologies focused on the country level and eight out of twelve methodologies focus (also) on the value chain (link) level. To ensure comparability, the definition of FLW should be set, the scope of the research should be clear, and formulas for data analysis should be set. Methodologies that are highly adaptable to a specific context (e.g. specific supply chains or processes) may be more attractive to businesses but often lack comparability. An open question remains whether comparability should be paramount in these contexts, if it entails a trade-off with the achievement of context-specific insight that may be more readily actionable for an actor looking to implement an intervention.

3.3 Accessibility and laboriousness

a) Extensiveness of documentation

The extensiveness of the documentation relates to the size of the document. Some quantification methodologies provide a description in 20 pages or less, some around 50 pages, while other methodologies need more than 100 pages to elaborate the methodology in full detail (Table 4). FAO (2018b), WRI (2016), EU FUSIONS (Tostivint et al. 2016), UNEP (2014), UNEP (2020), and APHLIS (Hodges 2013) are documents of more than 100 pages. The estimates provided by APHLIS on their website can be used without reading any document (APHLIS, 2020). However, when one wants to understand how the data was gathered or wants to collect their own data, the system is supported by a document of more than 100 pages. CEC (2019), FAO (2018a), IFPRI (Delgado et al. 2017) and GIZ (2015) provide documents around 50 pages. WRAP (2018) is 21 pages long. However, it refers to many other documents for the context and suggestions for other methods to use – for example WRI. Rockefeller (2016) is a document of seven sheets and therewith the shortest document to read but does not come with specific guidelines.

Here there is an obvious trade-off between the accessibility of the documentation and the thoroughness of description. While the extensiveness of documentation is only a very rough proxy, it gives at least an indication of the effort required to familiarize oneself with the methodology.

Table 4 Laboriousness summary

	Read [a]	Build [b]	Execute [c]	Perform [d]
WRAP (2018)	≤20	Missing	Extended	No guidance
Rockefeller Foundation (2016)	≤20	Missing	-	No guidance
FAO (2018a)	±50	Complete	Simple	Guidance
IFPRI (Delgado et al. 2017)	±50	Complete	Simple	Guidance
GIZ (2015a)	±50	Complete	Simple	Guidance
CEC (2019)	±50	Helpful	Depending on methodology	No guidance
FAO (2018b)	>100	Complete	Depending on methodology	Guidance
APHLIS (Hodges 2013)	>100	Helpful	Depending on methodology	Guidance
EU FUSIONS (Tostivint et al. 2016)	>100	Helpful	Depending on methodology	No guidance
UNEP (2014)	>100	Helpful	Extended	No guidance
UNEP (2020)	>100	Helpful	Depending on methodology	Guidance
WRI (2016)	>100	Helpful	Extended	Guidance

a Possible answers to select: ≤20, ±50, or >100 pages.
b Possible answers to select: missing, helpful or complete building blocks
c Possible answers to select: simple or extended execution, or depending on methodology
d Possible answers to select: Guidance or no guidance on analysis

b) Building blocks

Four quantification methodologies provide full documentation with building blocks that can be almost directly used to set up a (pilot) study. These building blocks can include example interview questions, survey templates, a thorough explanation how to set up a measurement in the field, or templates or forms to fill in collected information (FAO 2018a; FAO 2018b; Delgado 2017; GIZ 2015a). GIZ (2015a) provides different relevant tools in a toolbox, including participatory methods, checklists, data collection and evaluation sheets, and forms for documenting results. Both FAO (2018b) and IFPRI (Delgado et al. 2017) provide survey questions as building blocks to quantify losses, while FAO (2018a) provides building blocks for modelling the losses.

Six methodologies provide helpful insights to start with conducting a pilot or measurements (CEC 2019; Tostivint et al. 2016; WRI 2016; UNEP 2014; Hodges 2013, UNEP 2020), including documentation with the main steps the user must think about when conducting a pilot or measurement. Three of these methodologies also provide examples. For example, APHLIS (Hodges 2013) provides an example of a postharvest questionnaire and UNEP (2014) provide examples of a data reporting form, while WRI (2016) provides examples of what the reporting can look like. WRAP (2018) and Rockefeller (2016) provide limited documentation and concrete guidelines, and do not provide building blocks or steps to think about when starting measurements or a pilot.

c) Time to implement methodology

Not all methodologies come with a specified estimate of the time and resources required to implement it. Only GIZ (2015a) gives a quantitative indication of time needed to execute the method, recommending a month for a complete research cycle. For other methodologies, a rough indication of the time required can be based on the extensiveness of data collection that is required. The document of FAO (2018a) does not include instructions for gathering new data, but only uses existing data and calculations and is therefore relatively simple to execute timewise. The guidance documents of IFPRI (Delgado et al. 2017) and GIZ (2015a) are also relatively simple to execute timewise, since it consists of survey questions only or data collection consists of a desktop study and several rounds of meetings, workshops and roundtables.

The time required to execute measurements is higher compared to using secondary data or interviews. WRAP (2018), UNEP (2014) and WRI (2016) recommend direct measurements, and can therefore be expected to require more time to execute. Executing the quantification methodology of WRAP (2018) is time consuming as it refers to other documents with guidance on primary measurements (such as WRI) for the execution. The other documents analysed in this paper cannot be ranked based on the time to execute the methodology. Overall the documentation of these methodologies describes several different possible data collection methods, and therefore the execution time depends on the methodology that is selected (CEC 2019; FAO 2018b; Tostivint et al. 2016; Hodges 2013). The Yieldwise Food Loss Initiative is more of an umbrella initiative that includes several pilots, investigations, and actions (Rockefeller Foundation 2016). Overall, there is a trade-off between execution time (and corresponding costs) on the one hand and the level of detail and accuracy that can be achieved on the other.

d) Guidance on how to analyse the data

The time needed to analyse the data depends – apart from the very amount, nature and diversity of data collected – on the availability of guidance and formulas on how to analyse the collected data. In case guidance is provided, it will be easier and quicker to perform the analysis compared to finding out everything by yourself. Seven of the analysed documents provide this guidance by providing formulas (FAO 2018a; FAO 2018b; Delgado et al. 2017; WRI 2016; Hodges 2013; UNEP 2020) of which APHLIS (Hodges 2013) provides the user with a downloadable PHL calculator to estimate cumulative losses. GIZ (2015a) provides guidance on how to perform the data analysis or assessment of results during the different process steps. The other documents do not provide guidance on how to analyse the data.

To conclude, two out of twelve quantification methodologies have 20 pages or less, but also lack building blocks and guidance on the data analysis. Five out of twelve methodologies have around 50 pages, and depending on the methodology, can have complete, helpful or missing building blocks, and can provide guidance or no guidance on the data analysis. The five most extensive documents provide all helpful or complete building blocks, and the execution of the methodology depends on the selected methodology. Guidance on the data analysis can be present or absent. Overall four documents provide complete building blocks, are simple to execute (depending on the methodology selected) and provide guidance on the data analysis (FAO 2018a; FAO 2018b; Delgado et al. 2017; GIZ 2015a).

3.4 Practical guidelines or description

a) Practical (Interactive) tools

Most methodologies provide templates and tailored (interactive) tools to assist the user in implementing the methodology (Table 5).

Table 5 (Interactive) tools summary

No template available	Template available	Interactive tools
WRAP (2018)	EU FUSIONS (Tostivint et al. 2016)	APHLIS (Hodges 2013)
Yieldwise (Rockefeller Foundation 2016)	FAO (2018b)	CEC (2019)
APHLIS (Hodges 2013)	GIZ (2015a)	WRI (2016)
UNEP (2020)	IFPRI (Delgado et al. 2017)	FAO (2018a)
UNEP (2014)		

CEC (2019) refers to the Provision Coalition's Food Loss and Waste Toolkit which provides a step-by-step calculator to quantify the economic, social and environmental cost of avoidable food waste as it moves through the chain. Although it is intended for use by food and beverage manufactures, the principle behind it can be adapted for other sectors.[2] Besides the main document, WRI included three other documents for the practical implementation (WRI 2016). They included a 'Sample Reporting Template for FLW Standard' that helps users to record and report the results of inventories conducted using the FLW Standard. This interactive Excel tool includes both the required and recommended items and chapters described in the Standard. Furthermore, they added 'Guidance on FLW Quantification Methods' and 'FLW Quantification Method ranking tool'. The first document is supplemented to the FLW Standard and includes a thorough description of all FLW quantification methods, including an overview of the method, and a guidance description on implementing the method. The second document is an interactive tool that helps the user to select the best quantification method based on the wishes of the client based on a questionnaire.[3] FAO (2018a) provides a model to estimate FLW based on data from a 'representative basket of commodities', leaving the user some freedom in choosing which commodities to monitor (ideally they should represent a country's most important ones in terms of production value, and be distributed across five categories). The model produces an index of the percentage of food lost. Users can work with existing data from the Food Balance Sheets framework or gather more primary data using the guidelines provided by FAO (2018b). APHLIS (Hodges 2013) has a downloadable loss calculator, that allows users to input their context-specific information and produce loss estimates. The calculator itself runs on information from literature and expert assessment, which is still being expanded.

Other methodologies provide (static) templates for the user. Methodologically, RLAT (GIZ 2015a) relies heavily on participatory research instruments (interviews, expert consultations, focus sessions, workshops etc.), and provides templates for users to collect and structure the information gathered through these instruments. Users are encouraged to adapt their methodology to the local context. Also various (physical) measurements and estimates (by supply chain stakeholders) of losses can be collected and translated into aggregate estimates using the guidelines provided. IFPRI (Delgado et al. 2017) takes a somewhat different methodology, being based on surveys of producers, middlemen, and processors of specific supply chains by country.

[2] https://provisioncoalition.com/toolsandresources/foodlosswastetoolkit Accessed 19-08-2020
[3] https://www.flwprotocol.org/ Accessed 18-08-2020

The authors provide template questionnaires, a formula to determine the appropriate sample size, and formula to calculate the indicators that are relevant for their model. EU FUSIONS (Tostivint et al. 2016) provides examples and instruments, and the EU provides templates and documentation for this methodology.

The FLW quantification methodologies that are not accompanied by specific tools refer to other quantification methodologies for these tools (most commonly WRI and FAO), or offer general recommendations without specially developed guides or tools to assist users.

To conclude, most FLW quantification methodologies have one or more specifically developed tools to facilitate implementation by users. These tools differ in that they are aligned with the strategy and scope of the accompanying methodology, and work with either primary or secondary data or a combination of both, and can differ from (static) templates and documentation to more interactive (online) tools.

3.5 Reliability and validity

a) Data collection method

The availability, clarity, degree of detail, and ease of use of guidelines, procedures and tools (as described above) to a large extent determine the reliability (i.e. the extent to which the same methodology, when repeated in similar circumstances, produces comparable results) and validity (i.e. the extent to which a methodology measures what the user wants to measure) of a study. This section goes into more depth on the data collection methodology itself – keeping in mind that any FLW study can only be as reliable and valid as the method it is based on, and depends on the quality of implementation, analysis and interpretation (Table 6).

Table 6 Data collection method employed in surveyed methodologies

	Secondary data	Measurements	Estimates	None
CEC (2019)	x	x		
WRAP (2018)				x
UNEP (2014)	x		x	
RLAT (GIZ 2015a)		x	x	
Rockefeller Foundation* (2016)				x
APHLIS (Hodges 2013)	x	x	x	
FAO (2018b)		x	x	
EU FUSIONS (Tostivint et al. 2016)	x		x	
FAO (2018a)	x			
WRI (2016)	x	x	x	
IFPRI *(Delgado et al.* 2017*)*			x	
UNEP (2020)	x	x		

The quantification methodologies reviewed make use of different methods to quantify FLW. An important factor for the reliability of a study is the quality of the data and the reproducibility of findings when following the FLW quantification methodologies. Table 6 shows which methodologies rely on which type of data to be collected and worked with. The vast majority of methodologies offer considerable flexibility in the type of data users can use and/or collect.

While secondary data is (relatively) easy to collect, it does come with concerns about reliability (often hard to verify) and validity (due to the different purposes with which secondary data may have been collected, it is not necessarily directly representative for stakeholders with a focus on one specific system, chain, or process). However, collecting new primary data via physical measurements or arriving at reliably estimated values is more laborious. While self-reported estimates are less time-consuming than physical measurements, the validity of outcomes depends on the respondents' ability to accurately measure losses (Kok & Snel 2019). This can be safeguarded through the structure of the process through which they report and motivate their estimates. With these diverse data sources with respective advantages and disadvantages, most quantification methodologies give the user more than one option, depending on whether collecting primary data is feasible – if not, most methodologies accept secondary data as an acceptable proxy. Two reports offer no guidance at all in terms of data collection (WRAP 2018; Rockefeller Foundation 2016), but refer to other quantification methodologies or cover a selection of studies with a little overarching method. It is important to note that Table 6 only shows the method of data collection, not data treatment. For example, CEC (2019) details how participant measurements (kitchen diaries) can be used to estimate total food waste, in which case the data is collected through measurement, but an estimation is part of the analysis. The Food Loss and Food Waste Indices are entirely based on secondary data, but use inclusion criteria emphasizing quality primary measurement data.

In the diversity of quantification methodologies, there are considerably different definitions of reliability and validity, and the best way to achieve reliable measures, especially when collecting information from measurements or estimates. For example, whereas IFPRI (Delgado et al. 2017) instructs users to use a large enough sample size of survey respondents to elicit estimates from and offers a specific formula to calculate the appropriate sample size, the RLAT (GIZ 2015a) stresses careful selection of a small number of experts to provide motivated estimates. In fact, GIZ (2015b) emphasizes that statistical reliability is not the purpose of the tool, but rather quick insight through purpose sampling.

To conclude, the reliability of existing quantification methodologies is hard to compare, due to the variety of options offered to users in terms of data collection, and the reliability and validity of individual studies being influenced by the quality of the methodology used and the equality of implementation, analysis and interpretation. Overall, the flexibility of data use offered by existing methodologies underscores the observations that the laboriousness and resource requirements of a data collection methodology are prohibitive to the collection of high-quality primary data, and that the data and methodology should fit the user and their situation and questions.

3.6 Quantification methodology workflow and use case examples

Based on the criteria discussed above, and the workflows of the different methodologies, the methodologies are suitable to varying degrees to specific users, questions, and cases. In this section, we outline the process prescribed by the different methodologies, and illustrate in what type of situation this methodology would be suitable, drawing on examples from literature or (in the absence of available and clearly defined use cases) hypothetical examples.

CEC (2019) provides a step-by-step plan for how companies and governments can begin the process of measuring FLW with the goal to improve measurements of FLW cross the North American supply chain. It also provides opportunities to calculate its environmental and socioeconomic impacts. The guidance documents consists of seven steps of which the first three steps provide insights of why to create insight, while the other four steps give guidance on setting the scope, determining causes, identifying impact, and selecting and implementing the FLW measurement method. The first six steps are the same for all users in the supply chain, while step 7 is divided among sectors in the food supply chain to offer sector-specific information. For the scope definition and determining the causes the guidance document refers and summarizes the corresponding chapters of the FLW Standard developed by WRI (2016). The module on finding the causes is supplemented with examples of the difference between the cause and the root cause, the latter of which is also called 'driver' in the FLW Standard. The sixth module focusses on the three categories of impacts including environmental-, financial- and social impacts and provides references to toolkits, networks and models that can help the user to capture the impact. The last module contains guidance for different sectors on how to measure FLW. With help of different questions, the user can determine which method or methods are most appropriate in their specific situation. For every sector a case study is illustrated to emphasize the use of the guide in different situations. Examples ranging from a collaboration between the US state of California with the World Wildlife Fund (WWF) to collect baseline primary data and supported measurement on post-harvest losses of several crops to a bakery that wants to prevent FLW generation in western Canada.

FAO (2018a) defines the methodology for monitoring SDG Target 12.3 and more specifically the Global Food Loss Index design, data collection, methods and challenges. The goal is to monitor food losses on a global level for a basket of key commodities in the food system up to but not including the retail level, including crops, livestock and fisheries products, so that policy makers can monitor the trend regarding food losses compared to a baseline year in order to improve the food supply system efficiency against losses. The written paper includes the FLI design and presents the various elements of the methodology. The paper differentiates their methodology based on the availability of data - in case data exist or in case data is absent. In case the data is available, the paper describes the steps for calculating the index along with a method to aggregate data from subnational stages of the supply chain to the national level. In the case data is not yet present, the paper distinguished a short term methodology and a more long term methodology. The first methodology estimates food losses for the monitor which include improving the collection of data along the supply chain through nationally representative sampling and surveying, and other statistical tools, which are integrated in the national agricultural statistics systems, and the second methodology estimates model-base losses where data is not available in the short term and to model in interim data collection years. The paper shows some preliminary output of the model and GFLI calculations. A good example of where the model is applied is the Food Balance Sheet database provided by the FAO.[4]

Somewhat analogous to the Food Loss Index, the Food Waste Index "measures [total] food waste at retail and consumer level [...] (rather than loss or waste associated with specific commodities" (UNEP 2021). UNEP is custodian of the index, and is therefore responsible for the development of the index, and regular reporting and monitoring towards the target date of 2030 – by which food waste should be reduced by half according to SDG target 12.3. The Index is calculated overall and at the country level, based on available information.

[4] http://www.fao.org/faostat/en/#data/FBS

Depending on the quality of information available (and the resources available in countries to collect this information), the index works at three levels. At the first (most basic) level, food waste estimates for countries are imputed based on information from other countries. Ideally, all countries can at least follow the 'level 2' methodology, which includes regularly conducted direct measurement according to the quantification methodology. At the third level, enough information is collected to distinguish food waste destinations and disaggregate total waste by edible and inedible parts. UNEP publishes the Food Waste Database, with references to the information sources on which the index reports are based, the food waste estimates itself, and the confidence level they attribute to the estimates. Additional documentation provides member states with recommendations for methodologies to quantify food waste. The first global Food Waste Index report was published in 2021 (UNEP 2021).

The quantification methodology from FAO (2018b) focuses on harvest and post-harvest losses of food grains in developing countries. The target audience includes statisticians, administrators and decision-makers who are responsible for collecting data on food losses for grains. The guidelines enhance the strengthening and harmonization of data collection in the supply chain up and not including retail and final consumption. The methodology starts with the description of the rationale, scope and purpose of the guidelines, followed by the conceptual framework. Thereafter the principles for data collection and measurements are explained including the need to start with a proper agricultural value chain analysis prior to the main assessment, to fully characterize and decompose the chain and identify the processes where most losses are likely to occur. The next chapters describe different loss assessment tools that allow the user to learn more on the main PHL assessment methods like loss assessment through probability sample surveys, through field trials or regressing modelling. The document provided also a review of three other loss assessment methodologies; FAO 4S method, RLAT and APHLIS.

The set of principles written by WRAP (2018) shares knowledge and experience to help identify how best to measure food waste and take action to reduce it. The focus is on all types of businesses in the food supply chain. The user receives more information on three topics: The principles, global supporting resources and signposting to further industry resources, and is aligned with the FLW Standard. The principles provide a variety of case studies illustrating the practicalities of measuring food waste and the potential benefits. WRAP performed several case studies itself with different type of companies in collaboration with, or using, the FLW Standard as leading guidance. Case studies were conducted by WRAP in collaboration with the hospitality and food service sector, retailers, manufacturers, and logistics and redistribution organisations. Examples of case studies conducted include 'Measuring and reporting food waste in hospitality and food service', and 'Driving out waste in food & drink manufacturing and retailing'. WRAP (2018) also refers to the case studies on the website of the FLW Standard.

The quantification methodology proposed by IFPRI (Delgado et al. 2017) does not offer much flexibility. The methodology requires one crop to be selected up front, and the study focus is – due to the large sample sizes needed for the survey (hundreds of producers, middlemen and processors) – almost by definition at the country level (although a regional study in a sufficiently large region (e.g. Texas in the US) would probably be feasible). The chain activities are also defined up front, namely a rough division between producers, middlemen, and processors, with some assumptions about the activities they perform. The quantification methodology does offer some flexibility in terms of how losses are quantified, either in terms of quantity, quality, or price – although the authors consider it worthwhile to do all three – and allow triangulation of different estimation methodologies (subjective assessment, product price, visual crop characteristics, or formal quality classification of crops).

The workflow is straightforward: Once the crop and country are identified, the required sample size should be calculated (using a given formula based on country and product market characteristics), and the relevant models of the survey instrument administered to the required number of respondents in the three categories defined. Depending on the crop chosen, the survey instrument can be adapted, but to follow the analysis part of the protocol, essential elements should remain unchanged. The authors of the method also implement the methodology in selected value chains: Potatoes in Ecuador and Peru, maize and beans in Honduras, maize in Guatemala, and teff in Ethiopia. The results consist of loss estimates per level per country per crop. These high-level conclusions from highly aggregated information should prompt policymakers to prioritize tackling of food losses in specific crops and/or levels, but do not offer actionable insights for specific chain actors looking to improve their processes.

EU FUSIONS (Tostivint et al. 2016) developed the food waste quantification manual in order to support EU Member states in developing coherent methods for acquiring national data covering all sectors of the food chain. It focuses on monitoring food waste amounts and progression in the years, and how to report the results at country level. The quantification methodology starts with a description of the purpose of this document, and the terminology and definitions used in this manual. The largest part of the methodology describes the recommended method for a national food waste quantification study and per stage in the supply chain, including primary production, processing and manufacturing, wholesale, retail and markets, food service, and households. The structure for the recommended quantification methodology almost equal for all steps in the supply chain and includes scope and structure of the sector, identify and review existing data related to food waste, select the methodology for sectorial food waste quantification, using existing estimates or raw data and undertaking a study involving new measurements. The primary sectors also includes a sixth chapter on recording causes of waste. The manual can be used by EU Members states to guide them to the process of food waste quantification, and informs EU regulation in this domain. An example of a study where they refer to the definitions as set in the manual is a case study conducted in the Nordic countries on food waste quantification in primary production (Hartikainen et al. 2018).

The Food Loss and Waste Accounting and Reporting Standard (FLW Standard), developed by WRI (2016), consists of fourteen steps for quantification (monitoring) and reporting of FLW, and provides guidance to governments, companies and other entities. The first three chapters give more detailed information on the purpose of the standard, the definitions used in this document, and the goal of quantifying FLW. Thereafter the steps and requirements for FLW accounting and reporting are provided, which include defining goals, reviewing accounting and reporting principles, establishing scope, deciding how to quantify FLW, gathering and analyzing data, calculating inventory results, assessing uncertainty, performing review, reporting FLW inventory, and setting target and tracking these over time. For deciding how to quantify FLW, the user decides whether to undertake a new calculation and/or use existing data, and chooses the quantification method(s) to use in developing the FLW inventory. The FLW Standard is used widely, and information on different case studies is provided on the WRI website.[5] The case studies vary widely in the type of user (company or governmental organization), country of origin (from America till Uganda, or an analysis performed in several countries), step in the supply chain (from production till consumption) and type of product (from fruits and vegetables till dairy till palm oil).

[5] https://www.flwprotocol.org/case-studies/

For example the FLW Standard was used by Nestle to get more insight in their milk losses from farm gate to factory in 30 different countries, by Barilla to analyse the FLW for pasta from field to fork, that it produces in Italy, and by the State of Oregon to track food waste in both urban and rural households.

The RLAT (GIZ 2015a) consists of a sequence of ten steps, subdivided in three phases. The first phase consists of preparatory work (scheduling, training, desk research), the second phase constitutes the participatory assessments (roundtable, workshop, focus group, key informant meetings) and optional measurements, and the third consists of follow-up and reporting. This workflow is structured around the participatory process, rather than systematically zeroing in on loss estimates and hot spot assessments. GIZ has also published an "RLAT in action" report, showcasing the use of the RLAT for the case of maize losses in Ghana (GIZ 2015b). There is not a specific "problem owner" commissioning the study, but after the initial planning and desk research (yielding a high level map of the relevant value chain), a sample survey zone is selected within Ghana, from which subsequently participants are selected. This scoping and selection process remain quite diffuse. The document shows how the tool can be adapted for specific cases – in the case o maize for example quantifying corn loss by number of kernels. The vast and highly heterogeneous types of information collected show to be a challenge towards the end of the exercise, leaving the researcher to select the relevant information, triangulate from different sources, and draw conclusions and make recommendations. Although a fairly structured process, the volume and nature of the information collected still leave a lot of room for qualitative assessment by the researcher.

The guidance from UNEP (2014) defines its scope specifically as "food waste prevention in the retail, hospitality and food service supply chains, and household food waste." The guidance consists of four modules that facilitate the user working towards food waste prevention, of which the user can flexibly choose the elements that fit their context. Module 1 focuses specifically on mapping and measuring food and drink waste, whereas modules 2 through 4 cover prevention strategies for national and regional policymakers, household food waste, and business supply chain food waste specifically. The measurement module refers specifically to the WRI Food Loss and Waste Protocol as a quantification strategy, and offers some of its own suggestions for potential sources of data, either secondary or primary (e.g. kitchen diaries) – the UNEP guidance does not offer its own purpose-made measurement tool or strategy, but refers the user to relevant other sources in an integrative framework. The focus is predominantly on the country or regional level, but also allows the method to be used for individual business. Depending on the user's focus, quantification in module 1 should be followed by a prevention strategy one of the other modules (either a focus on the national or regional level, households, or businesses). In all three, relevant contextual factors and a list of options are presented, but a there is no direct link between measurement outcomes and selection of the appropriate prevention strategy. The protocol can be used by a wide range of users, but the high level constrains the scope to either national or regional administrative units in general, households within these jurisdictions, or companies in general. Modules 2 through 4 are illustrated with numerous case studies of specific prevention strategies in action, ranging from food use guidance labelling by British retailers to Japanese regulation to promote recycling of waste into animal feed.

The manual developed by Hodges (2013) as part of the APHLIS initiative focuses predominantly on cereal grains. The scope can be defined by the researcher, but is expected to be defined along a geographical/administrative dimension (i.e. local, provincial, national, but not necessarily a single actor or process). Hodges prioritizes rapid methods of estimation that give a representative result, allowing the user to justify interventions and track their performance.

The quantification methodology also has the specific aim of yielding estimates that can be contributed to the APHLIS database. The first phase is to plan the study, deciding on crop and scope. Secondly, the user has the option to do a questionnaire survey (a process specifically outlined by Hodges), or take (ongoing) loss measurements. A survey outcome could also be that measurements need to be conducted – if not, the study is complete. If measurements are taken, Hodges also provides instructions for this. From the data, cumulative losses from production are estimated. Chain mapping is not a part of this quantification methodology, as Hodges (2013) defines a limited number of relevant activities for cereal grains (from harvesting and field drying to farm storage and beyond to the market). Distinction between actors is also not a part of this FLW quantification methodology, with the implicit assumption that nearly all relevant activities are performed by African smallholder farmers. Based on this defined set of activities, a loss profile is compiled per country per crop, and further refined with new data. A typical case in which this methodology could be used is a specific cereal grain crop in a specific African country or region, grown mostly in a smallholder context.

The YieldWise Initiative was officially announced in 2016 by Rockefeller Foundation with the goal to reduce FLW by half in 2030. The initiative focuses on farmers in sub-Saharan Africa, where 70 percent of people rely on agriculture for their livelihoods. Rockefeller (2016) describes a systemic method to yield transformational change in five steps which include to ensure smallholder farmers can access technology and training to maximize yield and prevent losses, change behaviour and attitudes so that wasting food in unacceptable and increase accountability of minimizing loss and waste, encourage private investments that help farmers access existing solutions, involve small- and medium businesses, strengthen local commitments, and build partnerships within Africa that are mutually beneficial, and create alternatives to oversaturated local markets by building partnerships between smallholder farmers and multinational companies. Multiple case studies were conducted within the Yieldwise Initiative including a study on solar cold storage in the mango value chain in Kenya.

3.7 Key findings and gap analysis

This evaluation shows the multitude of tradeoffs involved in developing FLW quantification methodologies, and the aspects users should consider when choosing to use one methodology or another. For instance, they have to consider the following questions, which determine which quantification methodology is most suitable:

- Who is the user? Is the user a government considering the FLW picture at the country or regional level, or a private sector organization or non-profit interested in specific chains, processes or parts of the food system?
- What is the level of analysis (e.g. country, region, organization, supply chain, process)? This may correspond with who the user is, but not necessarily.
- Does the user need a methodology that yields comparable data, or a methodology that can be entirely adapted to the user's situation?
- What is the user's goal? Is the user interested in monitoring (Measure and Target) or in interventions as well (Measuring, Targeting, and Acting)? And between these goals, what does the user want to prioritize?
- What resources (time and money) does the user have available?
- Does the user require a step-by-step guide or interactive tool for the implementation?
- How much flexibility does the user want or need in choosing the data collection methodology?
- Does the user want or need to do primary measurements?

Overall, it is difficult to directly compare these quantification methodologies, since their goals are different. Quantification methodologies with the goal to improve data collection often entail a greater amount of work and are described in far more detail (FAO 2018b; Tostivint et al. 2016; WRI 2016). These quantification methodologies however often lack a strategy for action, and the question remains whether action in specific supply chains requires the most detailed high-quality information possible collected in a comprehensive and elaborate process. Quantification methodologies that focus more strongly on taking action against food loss (either at the policy level (e.g. WRAP 2018) or at the supply chain level (GIZ 2015a) rarely prescribe rigor and comprehensiveness in data collection, but rather emphasize the importance of actionable insights and a low barrier to rapid implementation (and additional costs) of the methodology.

Most questions above imply a tradeoff, for example between comparability and adaptability. The data gathered by governments or municipalities needs to be comparable, since they need to compare their results with those of other countries, or where different municipalities need one comparable methodology to be able to gather national data. The Food Loss and Food Waste Indices also require data to be comparable between countries, and for the available data to allow aggregation. On the other hand, businesses have a different goal. They are more interested in information that allows them to evaluate performance in their own specific processes over time, and to make informed supply chain investment decisions for targeted improvements. Most of the reviewed quantification methodologies were suited for either one goal or the other, an exception being APHLIS.

Laboriousness was divided in different criteria. Interpretation was based on the availability of a step-by-step approach. In that case it is easier for users to just follow the steps to receive the expected results (but again often entails a trade-off with flexibility). Three methodologies offer this step-by-step approach (Tostivint et al. 2016; WRI 2016; GIZ 2015a). The Yieldwise Food Loss Initiative is more an umbrella that includes several pilots, investigations, and actions (Rockefeller Foundation 2016), while the other methodologies describe (and recommend) different possible data gathering methodologies instead of one 'best' pathway. The amount of work was based on the throughput time, extensiveness of documentation, and a rough estimate of the time and resources needed for data collection.

The criterion 'practical guidelines or description' is based on the availability of user guides, templates, and (interactive) tools. Most quantification methodologies have one or more specifically developed tools to facilitate implementation by users. The tools are aligned on different levels with the quantification methodologies and work with either primary data, secondary data, or a combination of both. Templates and (interactive) tools facilitate easy implementation of the methodology. In cases they are not provided, methodologies often refer to other quantification methodologies for these resources or offer general recommendations without specially developed guides or tools to assist users.

The criteria reliability and validity includes the methodology of data collection itself. The reliability depends on the quality of the data and the reproducibility of findings when following the quantification methodologies, and validity depends on the extent to which a methodology allows a user what the user actually wants to measure. When checking the method of data collection that is described in more detail, eight methodologies describe two or more data collection methods that can be used, like collecting secondary data and performing measurements (CEC 2019), collecting secondary data and estimates (Tostivint et al. 2016; UNEP 2014), performing measurements and estimates (FAO 2018b; GIZ 2015a), or collecting secondary data, performing measurements and estimates (WRI 2016; APHLIS; UNEP 2020). FAO (2018a) only describes how to collect secondary data and IFPRI (Delgado et al. 2017) how to work with estimates from survey data.

However, the measurement methodology by itself does not say anything about the reliability, it is also dependent on the sample size, type of participants, professionalism of the data collectors, the execution of the data collection and the data analysis.

What seems to be missing from the current offering of quantification methodologies is an intervention-oriented methodology, that allows users (governments and private sector actors alike) to identify loss hotspots and implement appropriate actions easily (for example with a step-by-step guide), with limited work, and in a short period of time, relying as much as possible on available data and expertise, that is collected, analyzed and interpreted in a structured process to ensure reliability, and takes root causes of losses and waste into account for intervention selection. Existing quantification methodologies that do encompass the full Measure → Target → Act approach do not always recommend interventions aligned with the monitoring (i.e. measuring and targeting) phases (CEC 2019, GIZ 2015a), refer to other quantification methodologies for interventions (WRAP 2018), or recommend generic interventions with a very broad scope (UNEP 2014). A quantification methodology that recommends targeted interventions aligned with monitoring outcomes and an analysis of FLW causes is still lacking. Examples to build further upon to fill this gap include APHLIS (Hodges 2013), that is flexible, suitable for both government and private sector actors, makes structured use of available information, and ensured comparability between studies. However, this methodology lacks insight in causes of loss and does not provide a structured guide towards action. Another example to expand upon is the RLAT (GIZ 2015a), that includes an integrated strategy (Measuring, Targeting, Action), expansive tools and templates for easy implementation, and makes smart use of existing knowledge of supply chain stakeholders, that also ensures acceptability of interventions within a given food system. However, the RLAT lacks a structured methodology to weigh secondary data and estimates and does not assess loss causes when identifying interventions.

The next section discusses the design principles and features of a newly developed FLW quantification methodology that addresses these gaps.

4 Proposed new FLW quantification methodology

Among the FLW quantification methodologies surveyed above, we observe a wide variety in the way methodologies are designed and – accordingly – vary along the criteria defined: Strategy, genericity, accessibility and laboriousness, extent of practical guidelines or description, and reliability and validity. Considering all quantification methodologies' properties, we identify the need for a pragmatic, robust and intervention-oriented methodology with careful and logical alignment between the Measuring, Targeting, and Action phases, that is easy to implement for the purposes of a variety of stakeholders. We label this the EFFICIENT protocol: EFFectIve food Chain IntervENTion protocol.

These targeted interventions should be the main focus of this protocol (i.e. it should be intervention-oriented), with all steps building towards recommended interventions. Pragmatic entails that it is not too laborious or costly to implement – which would prohibit intensive use – but still allows for the best-informed intervention recommendations given the information and resources available. The protocol and accompanying tools and guidelines should be designed in such a way that implementation becomes an intuitive exercise. Using available data and expert judgement, it should be possible to implement the protocol in as short a period as possible in order to shorten the time to impact.

This extends to robustness, entailing that the protocol is evidence-based, and allows the user to quantify FLW, target hotspots, and implement interventions based on well-informed recommendations that are robustly supported by valid information about the user's context. In addition to these criteria, it should be easy to implement (also part of the 'pragmatic' criterium) with the help of well-documented guidelines and an intuitive tool. Last, it should be suitable for the questions and purposes of a wide variety of users, including governments, researchers, companies, NGOs and others in a way that it is adaptable for their purposes, but still ensures comparability.

In short, the proposed protocol should lower barriers to usage (i.e. based on easily available information, not too laborious to implement) and offer users a fast yet robust assessment of what interventions are necessary at what points in the chain. This motivates the formulation of the following leading design principles:

- It should be lean, requiring minimal effort for a useful result (in terms of understanding the supply chain, the food system, identify FLW hotspots, and proposed interventions).
- It should bring the focus quickly to FLW hotspots.
- It should minimize the use of direct measurements where existing information (secondary data, expert assessments) is available.

With these principles in mind, we propose a protocol that

- Estimates food loss and waste.
- Helps understand users better understand (their part of) the food system.
- Identifies FLW hotspots, causes of FLW and appropriate interventions.
- Assesses the effectiveness and sustainability effects of interventions.

The section below describes the design of the new protocol.

4.1 The EFFICIENT protocol

The described protocol is designed to quickly monitor FLW, identify hotspots, find causes and assess interventions in a step-by-step approach with use of limited resources. The definition of FLW is determined later in the protocol and not used as starting point. The protocol guides users through six different phases; Scoping phase, Food flow phase, Focus phase, Measurement phase (optional), Causes phase and Interventions phase (see Figure 1).

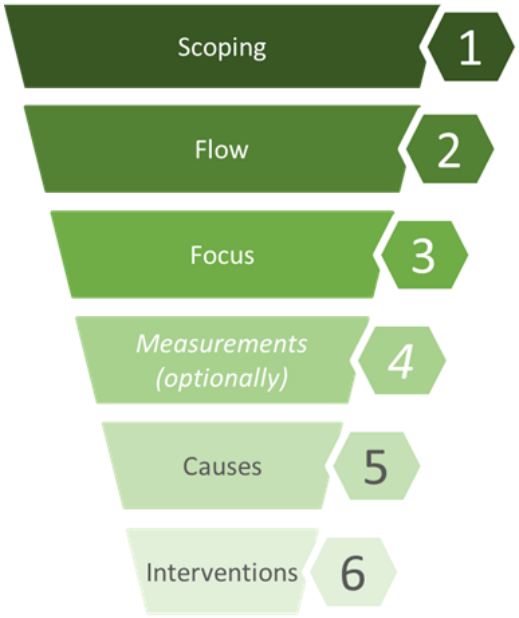

Figure 1 The EFFICIENT protocol

The protocol can be used in a project in collaboration with a client or used for own purposes. In the first scenario at least two people are involved; a client and an executor. A client can be a company, governmental organization (GO), non-governmental organization (NGO) or donor organization (DO) who is interested to start a project using this protocol. In case they hire or use a second party or person, like a researcher, student, consultant or employee to execute the project for them, we speak of an 'executer'. Both the executer and the client are the users of the protocol. In the second scenario only one person is involved who performs the role of the client, executer and user.

4.1.1 Scoping phase

The goal of the Scoping phase is to define the scope of the user's EFFICIENT study, which includes defining the boundaries of the supply chain or network, the geographical areas, the level of detail in product and time, and determine the required accuracy and detail of the data used in the process.

The scope of a FLW analysis is part of a food system, as illustrated in Figure 2 below. This can be an entire network, sector or a set of supply chains (case 1), (a part of) one supply chain (case 2), a horizontal coordinated organization like a cooperative or a chain of retail outlets (case 3), or one specific supply chain link (SCL) or process (case 4). These cases can be considered as building blocks, since they all have a recognizable interpretation. The result includes a list with the SCLs involved, like farmer, wholesaler, processor, and so on, and secondly, the result includes the number of actors in every SCL type in the scope (= frequency). In case transportation is not conducted by one of the supply chain actors, a transporter becomes a SCL in the scheme.

In every SCL, one or multiple actors can be involved dependening on the type of supply chain of interest. In case many actors are involved in one SCL, a generic protocol is more appropriate. In that case data is collected from a sample of actors in the SCL. The names of the actors in scope are not of interest, but merely views in general from experts, actors and stakeholders. An actor represents a role and interacts with a system in some way, while a stakeholder is a person or group of people who has responsibilities towards the supply chain and has interest in it. Overall an actor is always a stakeholder, but a stakeholder is not always an actor. In case specific actors in a SCL are selected, a specific protocol is more appropriate. In that case data is collected from the specific actors within scope and their name and address should be known. A combination of the two different protocols is also possible.

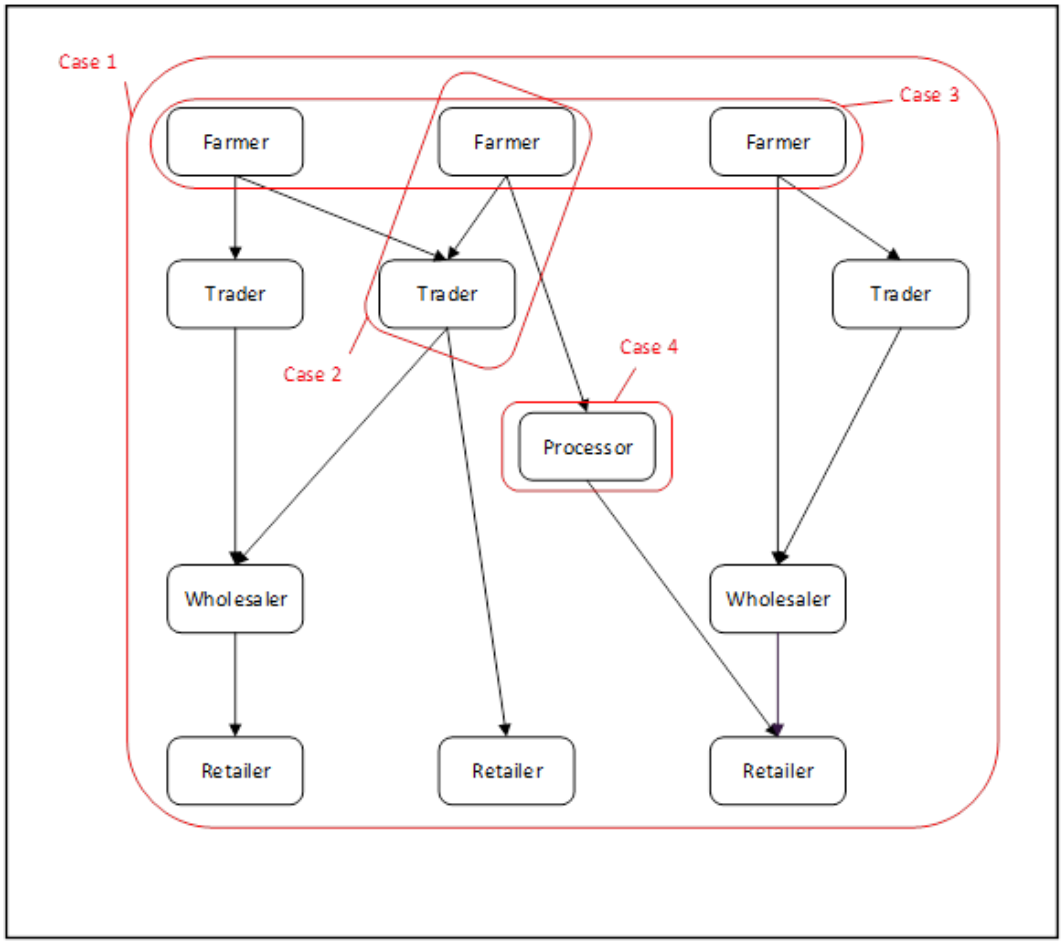

Figure 2 Examples of scope of analysis within a food system.

The Scoping phase consists of a questionnaire to decide the scope of the research (see Annex 1). It defines what part of the supply chain is included and what part is out of scope. This questionnaire can be filled in by the executer, the client, or together. In addition to defining the scope of the study, preparation for this questionnaire also consists of defining the goal of the study, searching for available sources in food production and FLW, and proposing experts who can help in chain mapping.

4.1.2 Food flow phase

The Food flow phase is aimed at understanding the food supply chain. The Food flow phase consists of two outputs. Output A is a food flow diagram including the selected SCLs with their connections. Also transport mode and transport ownership are determined. Output B is a quantitative flow diagram involving all selected SCLs, including per SCL an information table. For both outputs, the protocol includes a set of questions that helps to collect the relevant information.

The food flow diagram, output A, can be conducted by gathering information from the client, if possible supported by two experts, actors or stakeholders. Figure 3 shows an example of a combination of specific and generic SCLs and include two specific farmers, a specific trader, a specific processor and a generic wholesaler. Farmer Jo supplies produce to Mr. Dollar (picked up by Mr Dollar with a pickup car), and Mr. Dollar transports the produce to a wholesaler on the Nairobi main market. Part of the produce does not reach the market, but becomes a residual flow. In this case the residual flow is transported by Mr. Dollar to the Tropical Heat processor. Farmer Pete produces for the same processor and all of his produce is picked up by the Tropical Heat processor with their open truck. This food flow diagram can be made as simple or as comprehensive as necessary, depending on the scope of the study. In this example, farmer Pete may supply produce to another trader that is out of scope. However, it can be beneficial to draw this part of the supply chain to create a complete overview.

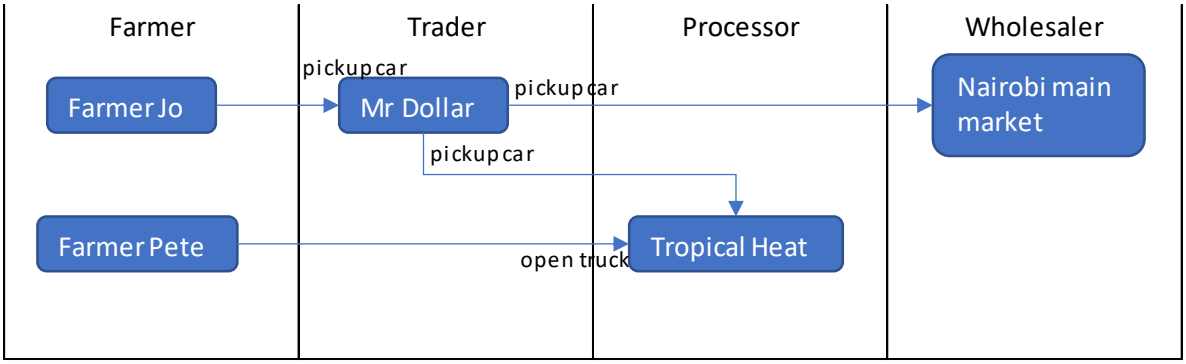

Figure 3 Example of a food flow diagram

Output B indicates the quantitative information per SCL or actor, including the yield or input volume, the activities that take place, the residual flow volumes and percentages, the destination of the residual flows, the sales volume, and the lead time. This part of the Food flow phase can be evaluated by including an expert panel of several experts, which can include the client, actors from the different SCLs or other stakeholders, like consultants, advisors, scientists or any other person who is involved in the supply chain. For every SCL or actor, information on activities and flows is collected based on estimates of an expert panel, relying on the principles of the Delphi method, and entered in a template as visualised in Figure 4.

title in the SCL box			
Yield or input volume/ selected time period (in tonnes) (1)	**... (tonnes)**	**Total sales volume (in tonnes) (5)**	**... (tonnes)**
Activities (2)	Tonnes deviated (3a)	% deviated (3b)	**destination (4)**
...		... %	...
	Lead time (6)	...	hours

Figure 4 Information table

The Delphi method
The Delphi method (Turoff and Linstone, 2002) is used to address a complex problem through a deliberative group process. These problems can range from design or policy issues to attempts to approximate unknown information - the latter being the objective of the Delphi approach in this protocol. In its most generic form, the administrator of the Delphi process distributes a questionnaire to a group of people (experts, users, or other stakeholders). The response is taken in, and based on the results a second-round questionnaire is developed, in which respondents can revise their original answers based on the group result (and optionally elaboration of respondents on the motivation behind their answers). Iteratively, this process should converge to a consensus – in this case an expert consensus on flows estimates.

4.1.3 Focus phase

The goal of the Focus phase is to prioritize SCLs or activities that are considered most urgent and promising for FLW reduction. The result of this phase is to create an overview with a prioritization of SCLs or activities that are considered most urgent and promising for FW reduction. This prioritization is achieved through conducting a multi-criteria analysis. Five selection criteria are included; FLW weight in tonnes/year and FLW weight in % relative to production/input in tonnes per year, investment space (in any currency possible), leadership in % change that a specific company or person take leadership, and time to impact in years (Figure 5). Information on the criteria can be retrieved from the information collected in the Food flow phase, and from client or expert consultation. Other desirable criteria, like environmental impact or political context, can be manually added by the user. After creating an overview of available data, the results should be discussed and the most relevant FLW steams for interventions or further research should be short-listed.

Pillars	Options	Relevant criteria
Desirability: Is reducing this FLW attractive from economic perspective?	FLW weight[I]	Tonnes/year that ends up in some destination
		Percentage of FLW (%) relative to production (tonnes/year)
	Investment space[II]	Tonnes/year FLW x price at stakeholder
Feasibility: Can we build on the stakeholders strengths?	Leadership[III]	% chance specific company or person take leadership
Viability: Do we 'believe' that 'it' can contribute to long-term FLW reduction?	Time to impact[IIII]	in years

Figure 5 Criteria for prioritization through Multi-Criteria Analysis in Focus phase

4.1.4 Measurements phase

The goal of the Measurement phase is to validate the expert estimates when estimations are uncertain, absent, or when more reliable data is desired. The Measurement phase can be skipped, or conducted after the Food flow phase, Focus phase, Causes phase or Interventions phase.

4.1.5 Causes phase

The goal of the Causes phase is to identify the root cause(s) of FLW for the prioritized SCLs or activities. The outcome of this phase will be a cause tree for the prioritized SCLs or activities which includes the root causes for FLW. The root causes can be found at two different ways a) manually, or b) with use of the cause tree tool. Finding the root causes can be done manually by interviewing actors by asking them about the root causes of FLW and drawing a cause tree. It is advised to use the '5 times why principle' (Williams 2001). Finding the root causes can also be done using the cause tree tool. The cause tree tool guides the user and interviewed actors finding the root causes of FLW and draws the cause tree automatically. An example of a cause tree with its root causes is shown in Figure 6.

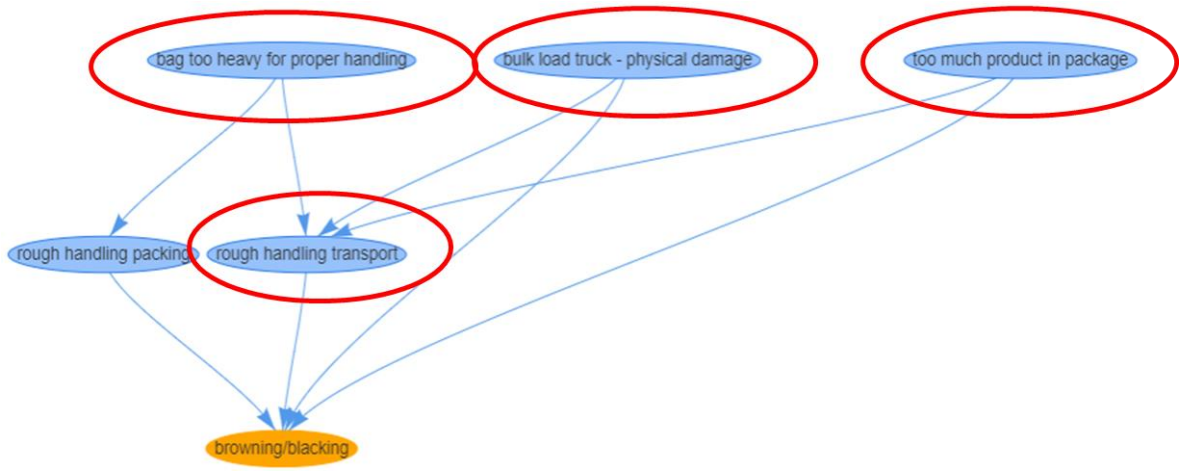

Figure 6 Example of a cause tree with root causes

Levels of food loss causes
Based on HLPE (2014), we distinguish three levels of food loss causes. The level at which the root cause is identified determines the type of intervention that is appropriate:

Micro: Causes are specific for one or two links in a particular supply chain – appropriate interventions are changes in practices, technological solutions or other investments in specific chain links.

Meso: Internal or external stakeholders of the supply chain and the way they are organized or relate to one another impact on FLW on the micro level – appropriate interventions are organizational changes.

Macro: Root causes lie in systemic issues in the food system – appropriate interventions are found at the policy and economic levels.

As there are plenty of interactions between these levels, we recommend to trace the root causes through a hierarchy of other causal factors. For example, a smallholder farmer may not be able to finance a specific technology that would reduce losses on their farm (micro-level) because of lack of access to credit (meso-level) due to a deficient financial system (macro-level).

4.1.6 Interventions phase

The goal of the Interventions phase is to provide interventions to prevent or reduce FLW. The result will be the selection of one or several suitable interventions, and the view of actors on implementing the intervention. The Interventions phase consists of two parts; a) a list of potential interventions and b) decision support. The list of potential interventions suggests a list of suitable intervention types based on the identified root causes found in the Causes phase. The user can select potential interventions per type (see Figure 7). In case several interventions are selected decision support is relevant to conduct. This part consists of three steps to help you to establish 1) what criteria you find most important, 2) decide upon an intervention, and 3) to create commitment.

Type	Intervention
Storage	Small-scale natural underground storage/cooling (root cellars), non mechanical
	Centralized storage facility
	Family-based storage facility
	Hermetic sealing metal silos and cans
	Storage room stacking practices
	Pest traps: insects and rodents, DIY
(pre)Cooling	Vacuum cooling, product enclosed in chamber where a vacuum is created, mechanical
	Cool packs
	Cloth shade structure
	Improved shade structures/sheds on field (de-heating)
	Pre-cooling with mobile water tubs (always use clean water)
	Misting or sprinkling with cool, clean water
Processing	Solar drying (direct or indirect)
	Mechanical drying
	Mobile drying
	Graters, choppers and slicers
	Fruit presses (juices and fruit wines)
	Canning e.g. Boiling Water Bath and Pressure Canners
	Ripening cambers at market place

Figure 7 A part of the intervention list with potential interventions divided per type of intervention

5 Conclusions

This paper outlined the methodological context and considerations underpinning the development of the newly proposed EFFICIENT protocol.

The protocol should be considered in the context of other, existing FLW quantification methodologies developed over the last years. Each of these methodologies offers something new and unique in addition to the others, and potential users can select the appropriate quantification methodology for their context, purpose, resources and other requirements. The first section of this paper presented a thorough comparison of twelve existing FWL quantification methodologies, including assessment on criteria defined in earlier academic literature, and an in-depth look at their workflow and suitability for different purposes. Within this body of work, we identified the need for a pragmatic, robust, and intervention-oriented methodology with careful and logical alignment between the Measuring, Targeting, and Action phases, that is easy to implement for the purposes of a variety of stakeholders. Therefore, this paper introduced a new quantification methodology: The EFFICIENT protocol.

The newly developed EFFICIENT protocol is based on design principles regarding the usability (a lean protocol that can be implemented with minimal effort for a useful result), insightfulness (the protocol should help users better understand (their part of) the food system) pragmatism (drawing on existing information when available) and orientation on action (quick identification of hotspots and appropriate interventions). More so than other quantification methodologies, the EFFICIENT protocol emphasizes a sequence of interconnected steps that are strongly aligned towards the end result of a loss-reducing intervention. Progressing through these steps allows a user to further elucidate and define their position in the food system and the actual problem(s) they are facing, and to identify loss hotspots based on available (or new) information through a structured process. Depending on the scope defined, the protocol provides a common denominator in monitoring progress on FLW reduction and provides food chain actors an accessible and solution-oriented tool to monitor their performance over time, identify (remaining) bottlenecks, and evaluate the efficacy of various interventions.

This paper and its methodological grounding offer two main contributions. First, the thorough comparison of different FWL quantification methodologies facilitates the selection of the right quantification methodology by potential users, possibly lowering the barrier to taking action on FLW. Secondly, the new EFFICIENT protocol meets a need previously not met by other quantification methodologies, hopefully motivating a wider range of actors to address FLW.

Both these contributions relate to the growing urgency of the issue of FLW, and associated challenges to food security and environmental sustainability. SDG Target 12.3 specifies the aim to reduce losses in food chains and halve food waste per capita by 2030. To achieve this goal, monitoring is necessary but not enough – insights from monitoring need to be translated to actionable recommendations in order to shorten the time to impact of FLW-reducing interventions in all parts of the food system. The EFFICIENT protocol provides an accessible tool for a wider range of stakeholders to accelerate action on this issue.

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Annex 1 Scoping phase questionnaire

Item	Question	Answer
0. General	Name of client. Name of organization client.	Open answer
1.Goal	What is the goal of your EFFICIENT study?	Open answer
2. Product	Briefly describe the food product of interest (Product category – product - variety)?	Open answer
3. Part of the supply chain/network/sector	Which SCL should be included? Select generic or specific actor. Include geographical region, or name and address.	Thick boxes and open answer
4. Indicator	How do you want to express the FLW? What unit per what time period?	Open answer
5. Availability of data source	Do you know of any available sources for FLW data?	Open answer
6. Quality of data	How do you consider the quality of these data?	Open answer on 1) Latest data available, 2) Reliability, and 3) Level of detail
7. Experts	Do you have experts in mind who may help identifying the determination of the food flow?	Open answer on 1) Name, 2) Function and organization, and 3) Contact

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Wageningen Food & Biobased Research
Bornse Weilanden 9
6708 WG Wageningen
The Netherlands
www.wur.eu/wfbr
E info.wfbr@wur.nl

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