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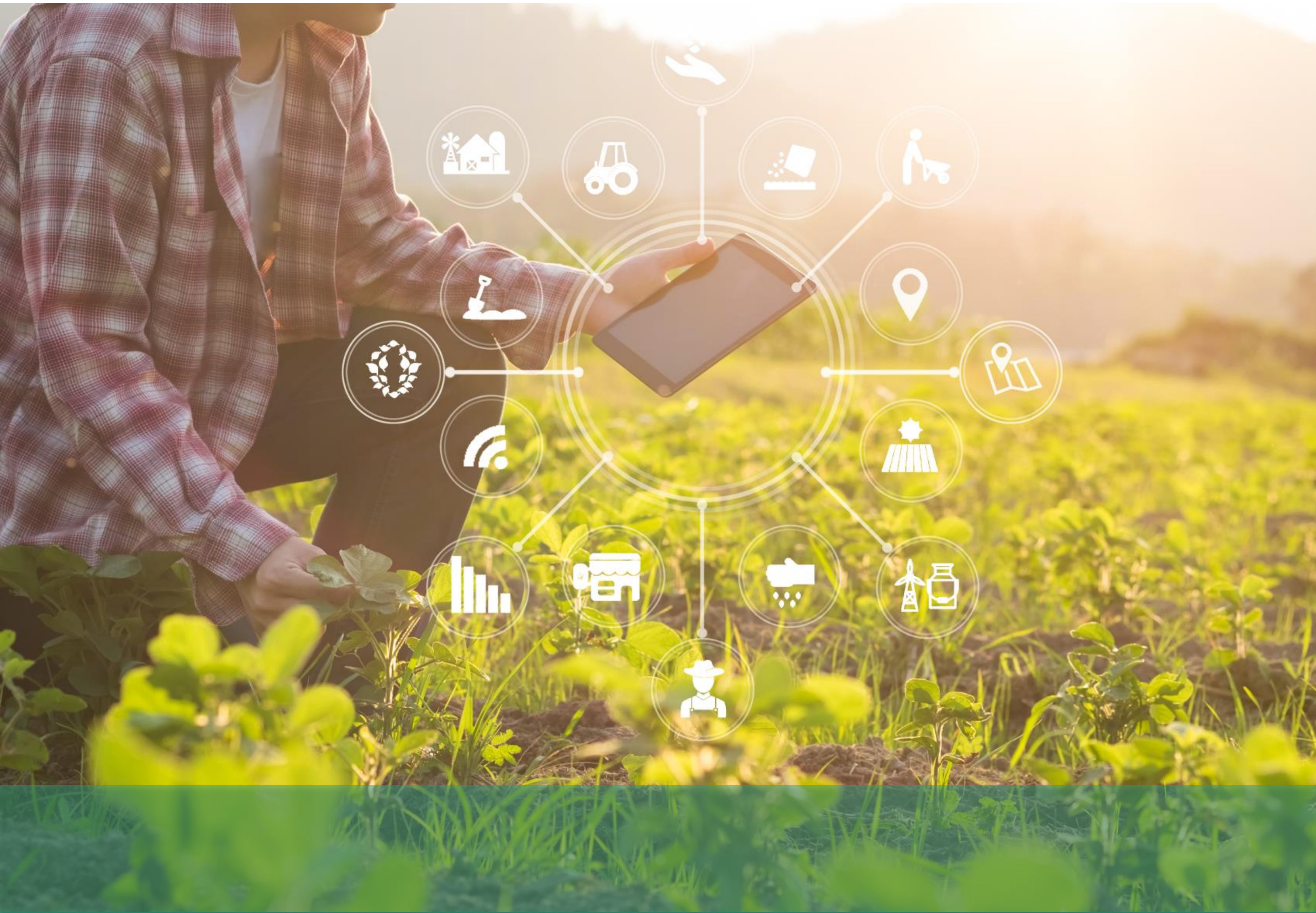

Technical Report

Quantifying Food Loss and Waste and Its Impacts

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WRI is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

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ABBREVIATIONS AND ACRONYMS

APHLIS	African post-harvest loss information system
CEC	Commission for Environmental Cooperation
CO_2	carbon dioxide
COD	chemical oxygen demand
COMCEC	Standing Committee for Economic and Commercial Cooperation of the Organization of Islamic Cooperation
Defra	Department of Environment, Food and Rural Affairs (United Kingdom)
ECCC	Environment and Climate Change Canada
EPA	Environmental Protection Agency (United States)
ERS	Economic Research Service (US Department of Agriculture)
FAS	Foreign Agricultural Service (US Department of Agriculture)
FAO	Food and Agriculture Organization of the United Nations
FLW	food loss and waste
FMI	Food Marketing Institute (United States)
FUSIONS	Food Use for Social Innovation by Optimising waste prevention Strategies
GDP	gross domestic product
GHG	greenhouse gas
INEGI	*Instituto Nacional de Estadística y Geografía* (National Institute of Statistics and Geography) (Mexico)
IUCN	International Union for Conservation of Nature
KFC	Kentucky Fried Chicken (until 1991)
KPI	key performance indicator
LAFA	loss-adjusted food availability
LCA	life-cycle assessment
NAFTA	North American Free Trade Agreement
NBS	Network for Business Sustainability
NCC	Natural Capital Coalition
NGO	nongovernmental organization
NRDC	Natural Resources Defense Council
ReFED	Rethink Food waste through Economics and Data
REFRESH	Resource Efficient Food and dRink for the Entire Supply cHain
Sagarpa	*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food) (Mexico)

SDG	sustainable development goals
Sedesol	*Secretaría de Desarrollo Social* (Ministry of Social Development)
Semarnat	*Secretaría de Medio Ambiente y Recursos Naturales* (Ministry of Environment and Natural Resources) (Mexico)
Semadet	*Secretaría de Medio Ambiente y Desarrollo Territorial* (Ministry of Environment and Land Development) (Jalisco, Mexico)
SETAC	Society of Environmental Toxicology and Chemistry
SIAP	*Servicio de Información Agroalimentaria y Pesquera* (Agri-Food and Fisheries Information Service) (Mexico)
UN	United Nations
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
VCMI	Value Chain Management International
WARM	waste reduction model
WCA	waste composition analysis
WRAP	Waste and Resources Action Programme
WRI	World Resources Institute

ABSTRACT

Food loss and waste (FLW) is an important issue in Canada, Mexico and the United States, where almost 170 million tonnes of the food produced for human consumption is estimated to be wasted across the food supply chain (CEC 2017b), while food security and resource efficiency are considered top priorities of the national social, environmental and development policies. The Operational Plan of the Commission for Environmental Cooperation 2015–2016 (Operational Plan 2015–2016) established the North American Initiative on Food Waste Reduction and Recovery as part of its green economy and climate change portfolios. This work is a continuation of previous work and is delivered under the Measuring and Mitigating Food Loss and Waste project in the Operational Plan of the Commission for Environmental Cooperation 2017–2018 (Operational Plan 2017–2018). This technical report is one of two outputs for quantifying FLW and food surplus; the other is a practical guide. The report discusses the methods for quantifying FLW and food surplus across the food supply chain and the approaches for estimating environmental, financial and social impacts caused by FLW and food surplus. It includes detailed information that supports the practical guide, allowing the latter to be a more user-friendly document. The two documents are designed to help governments, the food industry, businesses, institutions and nonprofit organizations better understand FLW and food surplus measurement at each stage of the food supply chain within North America.

EXECUTIVE SUMMARY

Developed with support and direction from the Commission for Environmental Cooperation (CEC), this technical report is about quantifying food loss and waste (FLW) and food surplus in the context of Canada, Mexico and the United States. This work follows the outputs delivered under the CEC Operational Plan 2015–2016, which established the North American Initiative on Food Waste Reduction and Recovery as part of its green economy and climate change portfolios. This report is one of two products (the other is a practical guide) delivered under the CEC Operational Plan 2017–2018, which continues the work as part of its Measuring and Mitigating Food Loss and Waste project.

Addressing these issues through trilateral cooperation supports governments, the food industry, businesses, institutions and nongovernmental organizations within the three nations to work toward a common goal of food waste prevention. The products of this project offer a consistency in approach that addresses common challenges while being sufficiently flexible to accommodate the different contexts within each country.

This report discusses the methods by which FLW and food surplus are quantified and the approaches used to estimate the environmental, social and economic impacts caused by FLW and food surplus. Working trilaterally draws expertise and cooperation from across North America and includes examples from all three countries and from around the world.

The practical guide that accompanies this report is designed to assist national and local governments, the food industry, business, institutions and nonprofit organizations in better understanding what to measure, and how to measure, to identify FLW and food surplus at each stage of the food supply chain for Canada, Mexico and the United States. This technical report contains detailed information and discussion designed to underpin the practical guide, allowing the latter to be a concise and user-friendly document.

SCOPE

For consistency, this report uses the FLW definition from the Food Loss and Waste Accounting and Reporting Standard (FLW Protocol 2016) and previous CEC reports (CEC 2018a; CEC 2018b; CEC

2018c). FLW refers to food loss and waste that is disposed of by landfill and incineration or treated by anaerobic digestion, industrial composting, or similar methods, including non-regulated ways. Excluded from the definition is food surplus, a term used for material available for recovery and redistribution to humans. The use of FLW in this report should not be taken as implicit endorsement of any particular definition or terminology. See Section 2.2 for more details.

FINDINGS

A number of useful findings about quantification of FLW are reported here.

Definition of and Reasons for Quantifying FLW

A number of definitions and terms are used to describe FLW and food surplus, and a number of terms are used to describe the same "flow" of food. Standardization would be helpful in this regard if enough flexibility remained to allow different organizations to focus on different aspects of the issue. Differences in terminology could be resolved by bringing leading organizations in this field together. In the absence of such standardization, the key recommendation is that organizations be explicit and clear about the definitions and terms that they are using.

There are many reasons to quantify FLW. An organization should define its objectives so that it has a clear understanding about what it wants to achieve.

Methods for Quantifying FLW

There is a range of quantification methods available, including:

- Direct weighing;
- Waste composition analysis;
- Records;
- Diaries;
- Questionnaire surveys; and
- Inference by calculation.

Each method has both strengths and weaknesses; for example, accurate quantification methods are often more expensive, while more affordable methods tend to be less accurate. Entities should consider the various compromises and trade-offs of any method. It is helpful if an organization has clear objectives and knows how the information gathered from the quantification method will be used. In many situations, it is possible to achieve FLW-related aims with rough estimates or even qualitative information (i.e., without any FLW quantification).

Businesses and governments often have different requirements when choosing quantification methods:

- Businesses tend to focus on their own part of the supply chain; however, some companies also consider their suppliers and customers. Most of the focus on quantifying household FLW is therefore carried out by governments and nongovernmental organizations (NGOs).
- Businesses tend to have direct access to their own FLW, whereas governments, NGOs and academics rely either on secondary data or on obtaining permission to access these FLW flows.
- Businesses quantify FLW for business reasons, followed by ongoing monitoring to ensure they achieve the intended savings. Governments quantify FLW to understand which sectors are national, state, or provincial priorities, and to develop policy and monitor progress against national and international targets.

Estimating the Environmental, Financial and Social Impacts of FLW

Estimating the environmental, financial or social impacts of FLW mostly relies on conversion factors that translate the weight of FLW to units useful in gauging these other effects. Environmental impacts are assessed on the basis of well-developed frameworks (mostly based on life-cycle analyses) that underpin calculations for greenhouse gas (GHG) emissions, water footprints and land use. Factors and calculation tools already exist and reasonable estimates can be made from a range of environmental indicators. Although methods to estimate the impact of FLW on biodiversity, energy use and fertilizer use exist, these are still being refined.

There is a wide spectrum of methods to estimate the financial impacts of FLW and food surplus. At the simpler end, calculations involve multiplying the weight of food waste by the cost per unit of weight. The factors used can account for a range of costs (e.g., waste management costs, cost of the ingredients, embedded costs added in the supply chain stage). The choice of factors should reflect the reason for estimating the financial impact. For example, to assess the financial impact of FLW prevention, all the costs that could be saved if the food is not wasted should be included. Using waste management costs alone can greatly underestimate the total cost of wasting food and have a deleterious effect on decision making.

More complex analyses consider how an economy may adjust in response to changes to FLW. Existing studies analyze the rebound effect and interactions between food sectors in the economy. There are currently few studies of this type and the estimates they contain are likely to be approximate. Nevertheless, they could help inform policy makers of some of the indirect consequences of tackling FLW, including effects on spending, gross domestic product (GDP) and jobs.

While estimating these impacts associated with FLW, it is important that studies describe what is being quantified. Usually, this is the gap between the current situation and a counterfactual (i.e., a hypothetical situation used for comparison purposes). It is recommended that the counterfactual be appropriate for the analysis in question and explicitly described.

Methods have recently been developed to estimate the social impacts of FLW (e.g., the nutritional content of FLW) and will likely be further refined.

Targets, Key Performance Indicators and Metrics

A range of key performance indicators (KPIs) and metrics[1] enable an organization to monitor progress toward a target to reduce FLW across the supply chain. These metrics fall into four categories:

- Weight-based metrics, which quantify the amount of FLW, food surplus, and so on;
- Impact metrics, which estimate the impacts of FLW;
- Facilitating metrics, which track changes necessary to bring about a desired change (e.g., the proportion of staff trained to prevent FLW, or the frequency of line failures); and
- Indirect metrics, which are not directly related to FLW but may correlate with FLW data. For example, in primary production, the amount of a commodity produced or sold per unit of input (e.g., fertilizer, acre of land) should increase as FLW is decreased, all other things being equal.

[1] It is common to use the terms “key performance indicator” and “metric” interchangeably. In this report, a key performance indicator is defined as a measurable value that is used to evaluate the success of an organization against a food waste prevention or diversion target and a metric is defined as a set of criteria that measure results.

There are many examples of weight-based metrics being adopted by businesses, NGOs and governments in North America. A majority of these focus on diverting FLW away from landfill; a smaller number focus on preventing food waste at source. There are a small number of impact and facilitating metrics in the public domain, but no examples of indirect metrics explicitly linked to FLW were found.

For only a minority of business KPIs are there published details of how they can be monitored and the exact scope of the metric. In addition, only a small number of metrics appear to be normalized; if done effectively, normalization leads to more appropriate comparisons over time by removing the effect of companies changing in size. The review of KPIs does suggest that there is merit in publishing guidance on how to develop, monitor and publish KPIs.

FLW and Food Surplus in North America

The Measuring and Mitigating Food Loss and Waste project has highlighted the similar challenges faced by businesses, NGOs and governments in Canada, Mexico and the United States. These include determining the appropriate method or methods to quantify FLW, using this information to estimate the impacts associated with FLW, and choosing metrics to track progress over time. These challenges are not unique to this region, although many of the examples of good practices included in this report come from North America. For quantification and estimations of impact especially, efforts to advance these fields are truly international.

Differences have emerged between the three nations (as well as within each nation) relating to the structure of the food supply chain. These differences include the nature of the FLW generated, the companies operating in each country, and the policy framework within which they operate. For instance, more FLW occurs in the consumption stages in Canada and the United States compared with Mexico, so focus on the consumption stages is relatively more important in the first two countries. Informal disposal routes are more prevalent in Mexico than in Canada or the United States and should be given special attention in that context. The types of food grown and manufactured in each country differ substantially. The countries also differ in the stage of development of their methodology for tracking progress toward Sustainable Development Goal 12.3. Nonetheless, the similarities are sufficient for a single practical guide to be useful and to steer businesses, governments and others toward relevant information.

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1 Introduction

This report was developed by the Commission for Environmental Cooperation (CEC) as part of its Measuring and Mitigating Food Loss and Waste project, a follow-up to the CEC's recently completed North American Initiative on Food Waste Reduction and Recovery. With a focus on quantifying food loss and waste (FLW) and food surplus, this report builds on the CEC's foundational research on food waste reduction and recovery and organic waste processing and diversion. It aims to address gaps in knowledge and opportunities for Canada, Mexico and the United States to benefit from a consistent approach to measuring FLW. Delivered under the CEC Operation Plan 2017–2018, this report and its companion piece, *Why and How to Measure Food Loss and Waste: A Practical Guide* (CEC 2019), round out a series of FLW publications in the CEC's green economy and climate change portfolios.

The CEC was established by the governments of Canada, Mexico and the United States through the North American Agreement on Environmental Cooperation, the environmental side agreement to NAFTA.[2] An intergovernmental organization, the CEC brings together citizens and experts from governments, nongovernmental organizations, academia and the business sector to seek solutions to protect North America's shared environment while supporting sustainable economic development.

CEC initiatives are undertaken with the financial support of the Government of Canada through Environment and Climate Change Canada, the Government of the United States of Mexico through the *Secretaría de Medio Ambiente y Recursos Naturales*, and the Government of the United States of America through the Environmental Protection Agency.

Working on these issues through trilateral cooperation expands and broadens experience, creates broader potential market opportunities for technological solutions, expands the audience for the CEC findings and helps to combine resources. This project identifies commonalities across North America while recognizing the specific nature of the issue within each country. As a result of this unique collaboration, the contents within this report and accompanying practical guide are relevant and applicable to all of those wishing to carry out FLW measurement regardless of their location.

The project seeks to achieve the following objectives:

- Improve measurement of FLW across the food supply chain, including approaches to correlate food loss and waste prevention, recovery and recycling with associated environmental and socio-economic impacts; and
- Practical actions and activities that facilities, organizations and governments can take to prevent, recover and recycle FLW across specific segments of the food supply chain.

This technical report summarizes and discusses FLW-related issues in the context of Canada, Mexico and the United States, drawing on examples from these three countries as well as relevant examples from around the world. The report's chapters follow this structure:

- **Background: definitions, frameworks and rationale** (Chapter 2). This chapter includes how terminology is used in practice, frameworks for conceptualizing FLW and food surplus, and how these both link to action to tackle the associated issues.

[2] Currently USMCA.

- **Quantifying the amount of FLW and food surplus** (Chapter 3). This chapter discusses a range of quantification methods, including emerging methods, with examples of these methods being used in practice across the food supply chain.
- **Estimating environmental, social and financial impacts and benefits** (Chapter 4). This chapter outlines the approaches that have been used and discusses the decisions that have to be made when estimating these impacts.
- **Metrics used for tracking FLW and food surplus** (Chapter 5). This chapter outlines key performance indicators and other metrics used in each supply chain stage. This section contains a discussion about how indicators link to the different objectives of organizations (e.g., prevention, diversion from landfill).
- **Key conclusions and recommendations** (Chapter 6). This chapter summarizes the state of affairs relating to quantification of FLW and food surplus in Canada, Mexico and the United States and summarizes the findings from the previous chapters.

In each of the chapters, the strengths and weaknesses of a range of approaches are discussed, as are the circumstances in which they are appropriate to deploy.

Accompanying this report is a separate product: a practical guide that is designed to assist governments, the food industry, businesses, institutions and nonprofit organizations to better understand FLW measurement at each stage of the food supply chain in Canada, Mexico and the United States. This technical report contains detailed information and discussion designed to underpin the practical guide, allowing the latter to be a concise and user-friendly document.

Both pieces of work build on recent publications, most notably on these:

- The *Food Loss and Waste Accounting and Reporting Standard* (*FLW Standard*) published by the FLW Protocol (FLW Protocol 2016). This multi-stakeholder initiative enables organizations (e.g., companies, countries, local governments and others) to quantify and report on FLW so they can develop targeted reduction strategies and realize the benefits from tackling this inefficiency.
- A foundational report and White Paper, both published by the CEC in 2017 and entitled *Characterization and Management of Food Loss and Waste in North America* (CEC 2017a, CEC 2017b). These publications propose comprehensive strategies to address source reduction of FLW, food rescue and recovery at all stages of the food supply chain, and reduced disposal of FLW.

This project has been prepared for the CEC by a consortium of two organizations: the World Resources Institute (WRI) and the Waste and Resources Action Programme (WRAP). The technical report and the practical guide have been developed with input from a group of experts convened for this project (see Acknowledgements). The Food Loss and Waste Measurement Expert Group comprises people with expertise in FLW measurement across the food supply chain acting together to tackle the associated issues. There is representation from Canada, Mexico and the United States, as well as experts from outside North America.

2 Definitions, Frameworks and Rationale

This chapter discusses the background to food loss and waste (FLW) quantification and estimating its impact. The chapter starts with an exploration of why organizations in Canada, Mexico and the United States might want to track the amount of FLW they generate and where it ends up (Section 2.1). The following section (Section 2.2) looks at the range of definitions currently used in North America and around the world, highlighting the differences that exist and stressing the importance of aligning the definition used and an organization's objectives. Section 2.3 discusses frameworks within which FLW is discussed in a wider context (e.g., sustainable materials management and the circular economy). Finally, Section 2.4 describes the sectors within the food supply chain and provides descriptions of these sectors in Canada, Mexico and the United States.

2.1 Why Quantify FLW and Food Surplus?

There are many reasons to quantify FLW and food surplus. This section discusses these reasons, which are highly relevant when deciding what to quantify and the approach to use.

The list below gives some of the main reasons for quantifying FLW (or food surplus). These are not mutually exclusive, and there is usually more than one reason behind a decision to quantify FLW. The quantifying organization may want to:

- **Develop an understanding of the issue.** This involves obtaining an estimate of the total amount of FLW and its associated value, gathering information on the types of food involved, and understanding why the food is being lost or wasted or has become surplus. This information can be used in deciding whether action is required, building the case for action (e.g., a business case) and developing solutions.
- **Prioritize action.** Closely linked to developing an understanding of FLW, this may involve identifying the hot spots of FLW (i.e., where there is a substantial social, environmental or financial impact). This can help in deciding where and how to start tackling the issue (e.g., deciding on which commodities, products or sectors to focus).
- **Evaluate a solution or initiative.** This is the process in which a combination of quantitative information (e.g., amounts of FLW) and qualitative information (e.g., observations) is obtained to understand if a proposed solution is having a positive impact. This may be during the piloting or testing phase of the proposed solution, or during the solution's full-scale deployment. This type of activity goes by many names, including program evaluation and policy evaluation. In addition, estimates of FLW may be used in a cost-benefit analysis to see if regulatory action would make economic sense.
- **Monitor targets.** This involves repeated quantification of FLW of a particular scope to determine trends over time. This information may be used to determine if targets (e.g., national, social, environmental, financial) have been met and may help in understanding whether all the solutions, initiatives and policies currently deployed have had sufficient effect.

There are several well-known targets relating to FLW. The sustainable development goals (SDGs) formally adopted by the United Nations in 2015 include Target 12.3, which calls for food waste to be cut by half by 2030. Many businesses operating in North America have aligned their own targets to SDG 12.3 or to the US goal announced jointly by the US Environmental Protection Agency (EPA) and the US Department of Agriculture (USDA) (see Chapter 5). There is a need to quantify FLW to ensure that progress is being made against this target and ultimately whether the target has been achieved. If this process is to succeed, the targets should be appropriate and closely aligned to the impacts that an organization is trying to achieve.

Generally, quantification for monitoring against specific targets requires accuracy in specific areas. For instance, if sampling of FLW is used, successfully monitoring targets requires larger sample sizes compared with the quantification used to develop a general understanding of FLW (e.g., for prioritizing action). Monitoring also requires consistency of definition and consistency of the quantification approach. These requirements are particularly important where the target represents a relatively small percentage change in the quantity being measured. For instance, if the target is a reduction of 15% in the amount of FLW, the confidence intervals will have to be much narrower than this to assess whether the target has been met.

Evaluations usually involve some form of measurement. Evaluations also gather other information to assess the effectiveness of the initiative. The exact nature of this additional information will depend on the nature of the initiative but could include interviews with those involved or the tracking of other metrics (e.g., sales or purchasing data, or attitudes of the public in the case of campaigns). Many academics call for a greater focus on evaluation of interventions and policies designed to tackle FLW, especially in the home (Porpino 2016, Stöckli et al. 2018).

Monitoring a target gives information about the general trend of FLW. However, it rarely provides information about which initiatives, programs or external influences led to any change observed. This is where evaluation of an initiative can play an important role. For instance, a company may start a program to reduce the amount of food surplus generated in its operations. This may have been rolled out across the company at the same time as constrained supply of and high prices for key ingredients occurred. Evaluation of the initiative would help in understanding the effectiveness of a change program, as well as the role of these other factors in influencing the amount of surplus generated.

In contrast, when developing a general understanding of FLW or prioritizing action, it is often possible to make good decisions with less accurate information. Approximate estimates of the amount of FLW arising in different parts of the food supply chain, or going to different destinations, can be sufficient to understand where the hot spots occur. These hot spots are often associated with food products or commodities with high volumes, rather than those with a high percentage being wasted. For example, potatoes and tomatoes contribute the most to FLW in US retail stores despite having lower loss rates (as a percentage of the amount of food coming into stores) than turnip greens, which have high loss rates (Buzby et al. 2015).

Monitoring and evaluation provide useful information, but usually must be supplemented with other types of knowledge to design interventions and make rational decisions to tackle FLW. It is important to understand why food grown to feed people ends up going into animal food, industrial uses, composting, anaerobic digestion, landfill or incineration. It is also important to understand why food is sent to a disposal option lower on the food recovery hierarchy, instead of to a more preferable disposal option such as anaerobic digestion or composting. It is important to understand the immediate reason for waste (e.g., food being thrown away because it has passed the date mark) as well as its root causes (e.g., mismanagement of food in the supply chain or home, a precautionary approach to date labels or improper packaging). Without this information, the design of potential solutions may be suboptimal and unlikely to tackle the underlying problem.

Finally, quantification can be used to assess broader issues related to FLW. For instance, many of the environmental benefits associated with food waste prevention relate to the embedded inputs of the food production systems (e.g., embedded GHGs, chemical inputs such as fertilizers and herbicides, land required for food production, irrigation water). This is because when food is wasted, the inputs associated with that food are effectively wasted as well.

2.2 Definitions of FLW, Recovery and Surplus

Many terms are used to refer to food that is not ultimately consumed by humans, leaves the food supply chain, or represents a financial loss to one or more companies. These include food loss, food waste, wasted food, surplus food, shrink, shrinkage, spoilage, by-catch, by-product, pre- and post-harvest losses, plow back, out-grades and so on. Some of these are used interchangeably, many overlap, and sometimes the same term is used to refer to food going to different destinations.

There is no universally agreed-on definition for any of these key terms. The European Union's Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) organization has identified more than 100 definitions of "food loss" and "food waste" (FUSIONS 2016). Neither this technical report nor the accompanying practical guide exclusively endorses any particular definition of food loss and waste. Instead, these documents lay out a framework of key variables to be adjusted to fit a range of scenarios. An organization's definitions should be aligned with its reasons for quantifying food loss and waste and should be tied directly to its desired outcomes.

Definitions can (and arguably, should) differ even between different agencies of the same government, depending on each agency's focused interest in food loss and waste quantification. For example, in the United States, the USDA focuses largely on food availability while the EPA focuses largely on the environmental impacts of food disposal and its implications for natural resources and climate change.

It is important to understand the definitions used in each study and care should be taken when comparing data and information across studies. Not only are there different definitions of the measured variables (e.g., shrinkage, food loss and food waste) but studies may also use different reference bases (e.g., volume of sales or food supply values or quantities or weight delivered; edible or non-edible food), and different areas of coverage (e.g., stages in the farm-to-fork chain, such as at the farm, store or household; or the specific fruits, vegetables and mixtures covered) in the analyses (Buzby et al. 2015, 626–48).

No definition discussed is universally used, but each is appropriate in a particular context and to achieve a given set of objectives. For the sake of clear communication, this report uses language consistent with the *FLW Standard*.

For this report, FLW is used as a general term to refer to food loss and waste being disposed of, including via landfill and incineration or treated via anaerobic digestion, industrial composting or similar activities. Food surplus is excluded from this working definition of FLW, a term used for material available for redistribution for human consumption. The relationship between FLW and overconsumption (i.e., populations consuming, on average, a greater number of calories than required to maintain a healthy body weight) has been discussed in the academic literature. For example, the effect of overconsumption alongside FLW has been assessed with respect to food security and the environmental impacts have been analyzed (Smil 2004; Alexander et al. 2017). Overconsumption is not considered to be a form of FLW in this report. The use of FLW and other terms in this report should not be taken as an implicit endorsement of any definition or terminology.

When direct quotes from other works appear, the original terminology from that study is used. However, when such studies are discussed, the terminology described above has been used to avoid confusion, especially when comparing studies using different terminology or definitions.

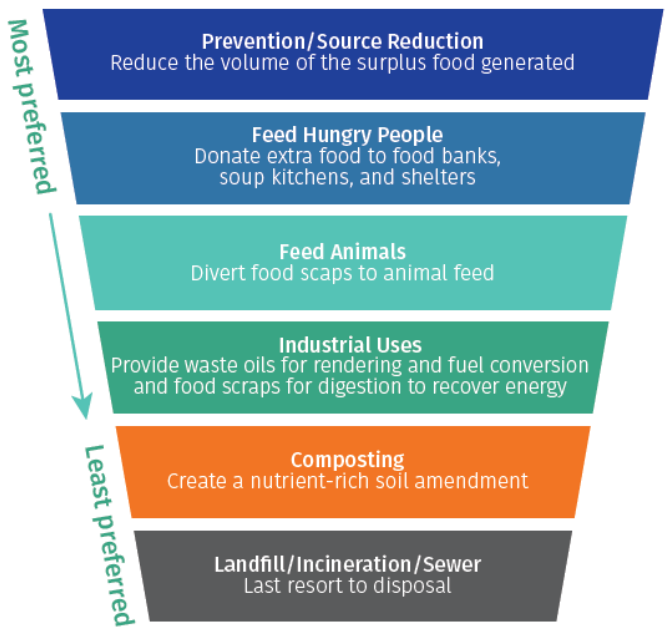
In addition, "quantification" is used in this report to refer to estimating the weight or volume of FLW. This is used in preference to the term "measurement," as not all the methods mentioned involve measurement; many are based on calculations to infer the amount of FLW (see Section 3.6). Therefore, "measurement" is a subset of "quantification." Quantification methods or quantification approaches, discussed in detail in Chapter 3, refer to specific techniques or a collection of techniques of directly measuring or indirectly calculating the amount of FLW.

2.2.1 Destinations

Food or associated inedible parts that leave the human supply chain go to a variety of destinations. These destinations include disposal (landfill and incineration)[3] and treatment (e.g., by industrial composting or anaerobic digestion). Disposal to sewers is also recognized in this report as a disposal destination.

The food recovery hierarchy (Figure 1) developed by the EPA is a clear way to visualize the relative merit of using each of these destinations. It is similar to other food recovery/waste hierarchies in existence. The EPA hierarchy focuses on the processes used to convert material exiting the food supply chain rather than on the ultimate output.

Figure 1. Food Recovery Hierarchy



Source: Adapted from EPA 2016a.

This technical report and the accompanying practical guide both aim to be consistent with this hierarchy. The highest priority is to help organizations prevent the generation of FLW; this usually confers the greatest positive environmental and financial impacts.

Far too often, organizations focus only on diversion from landfill and fail to address root causes of FLW generation and implement meaningful change to prevent FLW at source. However, in cases where FLW is still generated, the Measuring and Mitigating Food Loss and Waste project aims to help organizations move FLW up in the hierarchy, away from disposal destinations (e.g., landfill)

[3] In the case of Mexico, this includes both formal (i.e., managed) and informal (i.e., non-regulated) dumping sites.

toward treatment destinations (e.g., anaerobic digestion), feeding animals or redistribution into feeding people. The outcomes and destinations higher in the hierarchy of disposal destinations (e.g., feeding animals) have greater economic, environmental and social benefits than those lower in the hierarchy (e.g., landfill or incineration).

2.2.2 Why Define FLW?

Defining FLW is a necessary step in setting goals or objectives. Additionally, the quantification methodology should be consistent with the definition used. This ensures that what is measured is appropriate to the issue being tackled. For example, if one is interested in the effects of FLW on food security, resource efficiency or economics, one's selected definitions and methodology should be tailored to these issues (Chaboud and Daviron 2017). If food security is the primary objective of a policy, the definition of FLW should primarily focus on the wasted food (i.e., edible parts) of FLW and the inedible parts should either be of secondary importance or excluded altogether. In contrast, if resource efficiency is the motivation behind a policy, the inedible parts of FLW may be roughly as important as the wasted food.

These frameworks are still evolving to ensure that they continue to be useful. Alongside this work on quantification of FLW in North America, for example, a framework to support action across the whole food supply chain in Canada is currently being developed (VCMI 2018).

2.2.3 Defining FLW and Food Surplus

The following organizations have established different definitions of food loss, waste, recovery and surplus. These provide good signposts for an organization getting started in quantifying FLW and its impacts, and each applies to a different framing of the relevant issues for each organization.

Prominent examples of definitions of FLW include:

- **UN Sustainable Development Goal Target 12.3**
    - "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (United Nations, no date).
- **Champions 12.3** developed *Guidance on Interpreting SDG Target 12.3*. This definition is tailored to the global nature of target SDG Target 12.3 and its place under SDG 12, which focuses on responsible consumption and production (Hanson 2017):
    - Food loss and waste, as defined with the *FLW Standard* (FLW Protocol 2016) are grouped together under the "50% reduction" target.
    - Both food and its associated inedible parts are included.
    - All destinations are included, except animal feed and bio-based materials/biochemical processing (where material is converted into industrial products). This interpretation means the target is effectively a "prevention" target, rather than a "diversion from disposal" target.
- **UN Food and Agriculture Organization (FAO)**
    - Developed the *Definitional Framework of Food Loss*. This definition focuses mostly on the food security dimension of the problem.
    - "Food waste is a *part of food loss*, however not sharply distinguished."
    - Includes food but excludes its associated inedible parts.
    - All destinations outside of the human food supply chain are considered food loss and waste.

- **USDA and EPA**
    - In September 2015, the EPA and USDA jointly announced a national goal to reduce food loss and waste by 50% by 2030.
    - The USDA's Economic Research Service (ERS) defines food loss as the edible amount of post-harvest food that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (e.g., moisture loss), loss from mold, pests, or inadequate climate control and food waste.[4]
    - EPA defines food waste as "food such as plate waste (i.e., food that has been served but not eaten), spoiled food, or peels and rinds considered inedible that is sent to feed animals, to be composted or anaerobically digested, or to be landfilled or combusted with energy recovery."[5]
- **FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies)** developed the *Definitional Framework for Food Waste*. This definition is intended for a European context and is concerned primarily with resource efficiency (as it relates to the circular economy) and food security.
    - Food removed from the human food supply chain at any stage is referred to as food waste. Farm-level losses are not included in this definition.
    - Both food and its associated inedible parts are included.
    - All destinations are included except animal feed, biomaterial processing, or other industrial uses. These exempted destinations are generally termed "valorization and conversion."

Other associated terms are also used in this field, often with different meanings attached to a given term.

Surplus is a term often used for food products that are intended for sale but not sold. Surplus sometimes goes to disposal destinations (e.g., landfill), or treatment destinations (e.g., composting), but can also be redistributed via food donations to feed people.

Redistribution. Although most people would not define surplus food redistributed to people as food waste (i.e., it never leaves the human food supply chain), it is a term frequently applied to food donated with the intention of feeding people through food banks or other charitable services. Although food redistribution to people is socially vital, it can represent an economic loss for the donating organization. There are also environmental impacts associated with food redistribution, for example, many businesses only donate food nearing the end of its life (i.e., with a short shelf-life remaining). In addition, this term is sometimes applied to food that is used to feed animals.

Recovery is also a term used in several ways when discussing FLW:

- It is sometimes used to describe food diverted from disposal (landfills or another disposal option) to any other destinations (e.g., feeding people, feeding animals, anaerobic digestion).
- It is also used in a narrower way, including only diversion from disposal options to feed people or animals (excluding diversion from disposal to treatment methods such as anaerobic digestion).

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[4] See www.usda.gov/oce/foodwaste/faqs.htm and https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/loss-adjusted-food-availability-documentation.

[5] See www.epa.gov/sustainable-management-food/sustainable-management-food-basics.

Care should be taken when using terms and each should be carefully defined when it is used. In this regard, a degree of standardization across North America and beyond would be helpful, while maintaining flexibility to allow different organizations to focus on different aspects of the issue. This would help reduce misunderstanding and support prioritization based on the food recovery hierarchy. However, achieving a greater degree of standardization will not be straightforward.

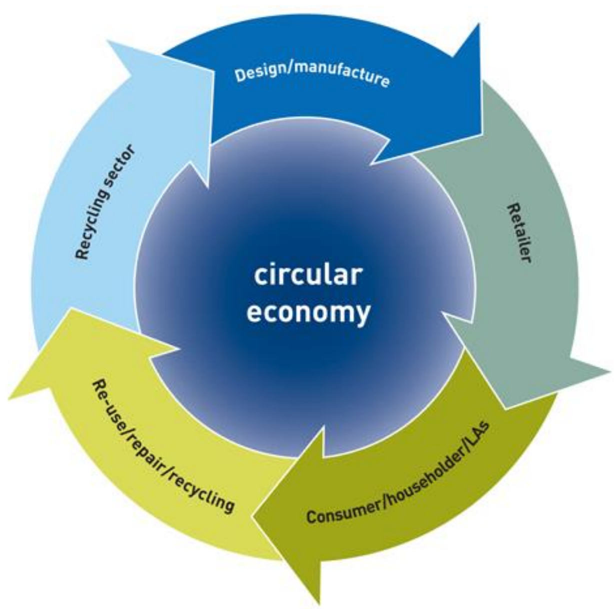
2.3 Frameworks and Blueprints for Conceptualizing FLW

This section describes how FLW fits within the context of relevant sustainability frameworks: the circular economy, sustainable materials management and the SDGs. In keeping with the food recovery hierarchy, the primary focus of this discussion is on how the prevention of FLW fits within these conceptual frameworks. It also discusses how moving food up the hierarchy fits within these frameworks.

2.3.1 Circular Economy

The circular economy can be defined as "an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them while in use, then recover and regenerate products and materials at the end of each service life" (WRAP 2018a). Similarly, the circular economy model advances economic activity that builds and rebuilds overall system health rather than just focusing on maximizing economic returns (MacArthur Foundation 2018). Figure 2 shows one simple portrayal of a circular economy approach.

Figure 2. A Circular Economy Cycle



Source: WRAP 2018a.

The circular economy approach provides an alternative to the typical extractive view of food and resource use. Rather than emphasizing a system in which food is produced and discarded to landfill, it promotes several of the intermediate steps in the food recovery hierarchy, such as composting and industrial uses. These intermediate steps extract the maximum value from the food produced in situations where it has become FLW. In this way, the circular economy approach can be a useful way of reframing the operations of a business toward a more sustainable approach in which resources are conserved and reused.

One possible limitation of the circular economy approach is that, in its emphasis on recycling and reuse, it may inadvertently encourage reuse and recycling at the expense of source reduction or FLW prevention. This is because source reduction is not explicitly included in the basic circular economy framework. However, if FLW prevention is included in a circular economy approach, it can still align with the food recovery hierarchy.

2.3.2 Sustainable Materials Management

Sustainable materials management is another approach which emphasizes the need to reduce global consumption of resources (EPA 2017). Sustainable materials management includes source reduction or prevention and tends to be focused toward environmental outcomes, as compared to the economic focus of the circular economy approach. An example of a sustainable materials management approach can be found in Figure 3.

Figure 3. A Sustainable Materials Management Cycle

Source: EPA 2017.

The materials extraction portion of the cycle can incorporate source reduction measures and the end-of-life management principles of the food recovery hierarchy. Like the circular economy approach, a sustainable materials management approach provides an alternative to an extractive view of food production.

2.3.3 Sustainable Development Goals

A third way of thinking about FLW and sustainability comes from the sustainable development goals (SDGs) adopted by the member states of the United Nations in 2015. There are 17 SDGs, with 169 targets within those goals to be achieved by 2030, some of them as early as 2020. The strength of the SDGs is in the bold, ambitious targets they set for global sustainability, which can encourage action from businesses and governments, as well as society in general.

For FLW, the most relevant goal is SDG 12: to "ensure sustainable consumption and production patterns" (UN, no date). Within SDG 12 is Target 12.3: "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses."

Numerous countries and companies have taken goals that are aligned with Target 12.3,[6] which has also been promoted by Champions 12.3, a coalition of high-level representatives from governments, businesses, international organizations, research institutions,= and civil society focused on achieving Target 12.3 (Champions 12.3 2018a).

2.4 Sector Descriptions

The practical guide accompanying this technical report has divided the food supply chain into several stages (sectors) to provide tailored guidance to each user community. For each sector, a brief description is given, followed by information for each of the three countries covered by this report.

2.4.1 Primary Production

The primary production stage in the food supply chain encompasses agricultural activities, aquaculture, fisheries, and similar processes resulting in raw food materials. This first stage in the food supply chain includes all activities related to harvest, handling and storage of food products before they move to processing or to distribution. Examples of activities within this sector are farming, fishing, livestock rearing and other production methods. Harvest activities are included within this sector, as well as post-harvest handling and storage. Any kind of processing of these raw food products would not fall within this stage of the supply chain but would be classified as processing and manufacturing.

Food losses in primary production can be caused by any number of factors, including pests, inclement weather, damage incurred during harvest, lack of ideal storage infrastructure, cosmetic or size requirements including retail standards and economic or market variability (e.g., cancellation of orders, rigid contract terms, or price variability and high labor costs).

The following is a non-exhaustive, illustrative list of approaches to reduce FLW generation within primary production:

- Working with actors downstream in the food supply chain to increase the share of second-grade products that are accepted and valorized to some point;

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[6] See SDG Target 12.3 on Food Loss and Waste: 2018 Progress Report (Champions12.3 2018b) for a list of countries and companies that have adopted FLW reduction targets that align with SDG Target 12.3.

- Improving cold chain management, availability and infrastructure to prevent spoilage or degradation during storage and transport; and
- Working with actors downstream in the food supply chain to expand value-added processing to increase the proportion of produced food able to eventually be consumed.

2.4.1.1 Canada

Canada produces nearly 35 million tonnes of food per year. This is equivalent to 1,050 kilograms of food per capita (FAO 2018). This sector contributes C$18.7 billion (about 1.1% of gross domestic product [GDP]) to the economy every year. Canada is a net exporter of food (Agriculture and Agri-Food Canada 2017). Primary production is mostly centralized in certain geographic regions and is dominated by large agribusiness companies. For example, more than 80% of total farmable area in Canada is in western Canada (i.e., Saskatchewan, Alberta and Manitoba) (Veeman and Veeman 2009).

Wheat is the top-produced crop, and Canada's food production is largely consolidated in its top five most-produced foods. These are wheat, rapeseed, maize, barley and milk. Pork is the most-produced meat but is followed closely by beef and poultry (FAO 2018; Statistics Canada 2017b).

An estimated 39% of all FLW in Canada occurs in the primary production stage of the food supply chain (29% occurring pre-harvest and 10% occurring post-harvest) (FAO 2018). These estimates are highly approximate and are dependent on the definition used for FLW. It would be beneficial to have greater consistency around the world to minimize the misinterpretation of estimates.

Market fluctuations are relatively drastic in Canada and can make proper forecasting difficult, especially when surplus goods from other countries are imported at below-market rates. Although there is generally sound storage infrastructure in Canada, inconsistent forecasting and market prices can cause FLW.

Private quality standards and grading standards for food products are strictly enforced in Canada, though there is no current estimate of this policy's effect on FLW generation (Government of Canada 2011).

2.4.1.2 Mexico

Mexico produced nearly 286 million tonnes of food in 2017. This sector contributes more than P$854 billion per year to the economy (SIAP 2018), or around 8.5% of GDP.

Mexico's most-exported food products are avocado (of which Mexico is the leading global producer and exporter), berries (of which Mexico is the 4th global exporter) and tomato (of which Mexico is the leading global exporter). Agricultural production is more diverse in Mexico than in Canada and the United States, where many commodities are produced in relatively equal proportions. Poultry meat dominates the animal products market, and beef and pork are produced in nearly equal levels. Many exports go to other North American countries. The United States is the top recipient of Mexican food exports, and Canada is the third. Compared with Canada and the United States, 24% of food production in Mexico is destined for self-consumption and involves smallholder farmers, with about 80% of farms smaller than five hectares (Oxford Business Group 2015, INEGI 2014b).

The World Bank estimates that in Mexico, about 20 million tonnes per year of food loss and waste arise from 79 products, from the farm gate to the point of food purchase. These 79 products represent 81% of total food purchased by an average Mexican household, representing over 35% of total food produced in the country. In addition, it is estimated (from urban solid waste and waste composition data from three states and thirteen municipalities) that there may be around 11 million tonnes per year of food waste from households and very small businesses. The amount of FLW in primary production (i.e., before the food leaves the farm premises) is still largely unknown. Therefore, the estimated scale of around 30 million tonnes per year is the lower boundary of a wide (but yet undetermined) range of FLW generated in Mexico (World Bank 2018, internal document).

Inadequate storage facilities and infrastructure (primarily cold-storage infrastructure and technologies to manage humidity) cause a disproportionate amount of FLW in Mexico when compared with Canada and the United States. This is especially true in the tropical and subtropical regions of the country.

2.4.1.3 United States

The United States produces the most food of North American countries, with a total of more than 344 million tonnes produced per year. This is the equivalent of 1,133 kilograms of food per capita (FAO 2018). This sector contributes US$136.7 billion (about 1% of GDP) per year to the economy, although the United States is a net importer of food (USDA ERS 2017).

Maize is the top-produced crop in the United States; maize production (by weight) is nearly four times that of soybeans, the second most-produced crop. The top five most-produced food products are maize, soybeans, milk, wheat and sugar beet. Poultry meat dominates the animal products market, and beef and pork are produced in nearly equal levels.

Several of the world's largest agribusiness companies are based in the United States, including Cargill, Archer Daniels Midland, CHS Inc., Land O'Lakes, Monsanto, Perdue Farms and Tyson Foods. Small farmers and food producers are numerous across the United States, but large companies tend to dominate the market. Agricultural production occurs mostly in the Midwest and in the valleys of the West Coast.

An estimated 36% of all FLW in the United States occurs in the primary production stage of the food supply chain (28% occurring pre-harvest and 8% occurring post-harvest) (FAO 2018). These estimates are highly approximate, however.

Significant amounts of crops are not harvested each year in the United States. Although the national average of cropland that is not harvested is around 7%, this figure can be as high as 50% in some areas in certain years (Gunders 2012).

In the United States, grading standards and requirements (e.g., size, shape, color) are especially strict. An estimated 10% of produce grown in the United States is wasted because of grading standards (ReFED 2016). Surplus food on the farm (most often caused by market fluctuations) is not often donated because of various factors, including the reluctance of growers to have volunteers on their land and the accompanying liability. Despite the 1996 Bill Emerson Good Samaritan Food Donation Act, which encourages companies and organizations to donate surplus food in the United States, lack of widespread awareness of the law means that food is disposed of instead of being used to feed people. Even though donations have few financial benefits for the producer, they play an important role in food security.

2.4.2 Processing and Manufacturing

The processing and manufacturing stage in the food supply chain encompasses all processes intended to transform raw food materials into products suitable for later consumption, cooking or sale. For the purposes of this report and the accompanying practical guide for measuring food loss and waste, "food processing" and "food manufacturing" are used as interchangeable terms. This stage in the supply chain includes the entire breadth of processes used to turn raw agricultural products into saleable goods, and these goods often move from this stage in the food supply chain to retail, wholesale, distribution, or food service institutions. It also includes packaging of said processed goods. Examples of organizations within this sector are fruit and fruit juice processing plants, cereal manufacturing facilities, pastry factories, canneries, butchers, breweries, bakeries and dairy processing plants.

FLW in processing and manufacturing can be caused by any number of factors, including trimming for consistency, misshapen products, spillage, degradation during processing, production line changes, contamination, overproduction, inaccurate demand projection, order cancellation, changes in customer demand or specifications, or improper labeling.

Food processing represents between 15% and 23% of the entire manufacturing industry (including nonfood manufacturing) in North America (USDA ERS 2017; Agriculture and Agri-Food Canada 2014; ProMéxico 2015).

The following is a non-exhaustive but illustrative list of approaches to reduce FLW generation within processing and manufacturing:

- Working with actors upstream in the food supply chain to increase the share of second-grade products that are accepted and valorized to some point;
- Improving cold chain management, availability, and infrastructure to prevent spoilage or degradation during storage and transport;
- Working with actors across the food supply chain to expand value-added processing to increase the proportion of produced food able to eventually be consumed;
- Standardizing date labels to reduce the amount of FLW generated from confusion over food quality and food safety;
- Implementing packaging adjustments to extend the life of food products and reduce damage during storage or transport;
- Optimizing manufacturing lines and production processes to increase yields and reduce inefficiencies; and
- Investing in new technologies to increase shelf life of food products.

2.4.2.1 Canada

Food processing is the largest segment of the Canadian manufacturing sector and constitutes 2% of the country's GDP (Agriculture and Agri-Food Canada 2016). Canadian food processers are highly centralized; 75% of all food production facilities (of which there are an estimated 5,700 in the country) are in Ontario, Quebec or British Columbia (Statistics Canada 2014; Statistics Canada 2017a). The four most economically impactful food categories for the sector are meat, dairy, beverage, and grains and oilseeds (Uzea et al. 2014).

FAO estimates that 11% of all FLW in Canada occurs in the processing and manufacturing sector, though others estimate that processing and packaging accounts for 18% of FLW in Canada (FAO 2018; Uzea et al. 2014). These estimates are highly approximate, however. Two of the most common causes for FLW generation among Canadian processing factories are poor inventory management and spoilage (i.e., due to inadequate packaging or inefficient processing [Uzea et al. 2014]).

2.4.2.2 Mexico

The 2016 value of processed food production in Mexico was 111.4 billion dollars. The processed food industry accounted for 23.4% of the manufacturing GDP and 3.9% of total GDP. Its added value was 37.4%; 54% of the production per industry was concentrated mainly in the categories of bakery-tortillas and meat processing, followed by milk products with 10%. (ProMéxico 2018). Mexico is also home to some of the world's largest food processers, especially of food products distributed through Latin America. Some of these companies are, for example, Grupo Bimbo, Femsa and Sigma Alimentos.

As previously mentioned, FLW occurs at all stages of the Mexican food supply chain, and even if there are sufficient data on FLW in Mexico to identify an indicative baseline of around 30 million tonnes, while also highlighting the hotspots, these data are not sufficient to accurately quantify the specific amount and types of food lost and wasted at different parts of the food value chain. Regarding manufacturing, processing and packaging, the World Bank reports that larger manufacturers have varying quality of production data that can give estimates of FLW (World Bank 2017, internal document).

FAO estimates that 18% of all FLW in Mexico occurs in the processing and manufacturing sector (FAO 2018). These estimates are highly approximate, however. Root causes of FLW generation in other North American countries may apply to the sector in Mexico and should be considered by a processing organization in Mexico as well. Common causes of FLW in other countries, such as trimming, overproduction, inadequate infrastructure or machinery, inefficient systems design, damage during packaging, inaccurate forecasting, food safety issues, cold chain deficiencies, and inconsistent quality may contribute to FLW in the Mexican food processing sector.

2.4.2.3 United States

The United States is home to some of the world’s largest food processing companies and facilities. Some of the largest companies are international brands, such as PepsiCo, Dole Food Company, Tyson Foods, Coca Cola, ConAgra Foods, Kraft Foods and General Mills (Ocano 2015). These companies operate globally in a wide variety of product categories, but their standard business practices have played a pivotal role in shaping American food manufacturing.

The largest food categories in the US food processing sector are meat, dairy, and grains and oilseeds. Meat represents a disproportionate portion of the value of the sector, contributing more than US$850 billion every year to the economy. By comparison, dairy (the second most valuable food category in the sector) contributes US$35 billion every year (USDA 2017).

The United States features relatively few numbers of processing and manufacturing facilities considering the amount of output, but these facilities tend to be larger in size. Despite being highly efficient, facilities in the United States often produce large absolute volumes of waste (partly because they simply manufacture more food products) and often focus on disposal destinations rather than prevention. Through targeted measurement, however, many are able to identify waste hot spots and opportunities for FLW prevention throughout their processing.

An estimated 11% of all FLW in the United States occurs in the processing and manufacturing sector (FAO 2018). These estimates are highly approximate, however. Some of the main root causes contributing to FLW generation in this sector are trimming, overproduction, damage during packaging and technical malfunctions.

2.4.3 Distribution and Wholesale

Food distributors and wholesalers act as a key link for food products to make it to market and consumption. They are subject to supply and demand fluctuations across the food supply chain and must balance time sensitivity and cost in their operations and business. Variability within the distribution and wholesale sector can also lead to FLW generation downstream, in the food service, retail and household stages. Examples of organizations within this sector are wholesale markets, food distributors and third-party logistics providers involved in food.

FLW in distribution and wholesale can be caused by any number of factors, including damage and spoilage, lack of cold chain infrastructure, delays during transport (e.g., border inspections), modification or cancellation of orders, product specifications, variable cost of transport methods, inaccurate forecasting or purchasing, and miscommunication with other entities further up and down the food supply chain.

As the specifics of this sector vary by country, so do the root causes behind the associated FLW. Generation of FLW and prevention of FLW differ from country to country and even organization to organization, and interventions must be tailored to the context.

The following is a non-exhaustive but illustrative list of approaches to reduce FLW generation within distribution and wholesale sectors:

- Improving cold chain management, availability and infrastructure to prevent spoilage or degradation during storage and transport;
- Working with actors across the food supply chain to expand value-added processing to increase the proportion of produced food able to eventually be consumed. This could include the creation of processes to valorize food that is damaged or deteriorates during transport and distribution;
- Implementing packaging adjustments to extend the life of food products and reduce damage during storage or transport; and
- Rethinking business models to maintain freshness and reduce shrink.

2.4.3.1 Canada

Around 3% of FLW in Canada occurs during distribution (CEC 2017b). As is common in most of the world, most of these losses are perishable goods such as fruits, vegetables, seafood and meat (Uzea et al. 2014). Most of Canada's food production occurs in the southern regions of the country, where most of the population also lives. Even along the southern border, however, the vast distances covered by food distribution can lead to FLW generation. This is especially true for those systems with outdated cold chain systems or infrastructure (Prentice 2016).

Food distribution in territories or regions farther to the north is complicated by extreme weather and distance. Conventional distribution and shipping methods are often impossible, and the few reliable methods for shipping food products tend to be both extremely slow and expensive (Prentice 2016).

2.4.3.2 Mexico

According to SIAP (2018), there are over 3,000 agri-food storage facilities in Mexico, and 90 wholesale centers. Nevertheless, food distribution and food brokering in Mexico may hold significant potential for future FLW measurement and reduction. Cold chain infrastructure, known to be one of the largest opportunities for preventing FLW generation, is limited and inadequate in many parts of Mexico (FAO 2011). This, paired with inadequate storage and transportation infrastructure for food, leads to high levels of FLW during distribution (Sagarpa 2010). Additionally, further inefficiencies in the Mexican food supply chain, such as the centralization of food wholesalers and brokers in urban centers, can lead to FLW. The centralization of certain distribution processes requires goods to travel to city centers for brokering and then their subsequent distribution. This process could be greatly streamlined and FLW prevented (Fundación UNAM 2013).

2.4.3.3 United States

Distribution networks in the United States are more expansive and varied than in Canada and Mexico. The prevalence of distributors and third-party logistics providers, along with good cold chain infrastructure, makes distribution relatively easy for others in the food supply chain (Snider 2018). However, this sector is subject to inaccurate predictions and market fluctuations that could lead to surplus food, FLW, or both.

On average, food travels 1,500 miles from farm to table in the United States (NRDC 2010). Although distribution networks are efficient in the United States, and are becoming even more so, the distance between production and consumption creates room for potential FLW generation.

2.4.4 Retail

Because of their strong buying power, retailers can influence FLW generation further upstream (i.e., in the primary production, processing and manufacturing stages) and even within the distribution stage. Also, because of their typical placement (right before final consumption and preparation) in the food supply chain, variability within the retail sector can also lead to FLW generation in the food service and household stages.

FLW in retail can be caused by any number of factors, including damage and spoilage, lack of cold chain infrastructure, delays during transport (e.g., border inspections), inaccurate customer forecasting and overstocking, reliance on inefficient stocking practices or product sizes, misinterpretation of food safety standards, and misleading or confusing date labeling.

As the specifics of this sector vary by country, so do the root causes behind the associated FLW. Generation of FLW and prevention of FLW differ from country to country and even organization to organization, and interventions must be tailored to the context.

The following is a non-exhaustive, but illustrative, list of approaches to reduce FLW generation within retail:

- Working with actors upstream in the food supply chain to increase the share of second-grade products that are accepted and valorized to some point;
- Improving cold chain management and infrastructure to prevent spoilage or degradation during storage and transport;
- Working with actors across the food supply chain to expand value-added processing to increase the proportion of produced food able to eventually be consumed;
- Identifying products with high consumer demand that also reduce waste generation;
- Standardizing date labels to reduce the amount of FLW generated from confusion over food safety and food quality;
- Implementing packaging adjustments to extend the life of food products and reduce damage during storage or transport; and
- Rethinking purchasing models and promotion strategies to maintain freshness and reduce shrink.

2.4.4.1 Canada

A majority of economic value in this sector is in supermarkets. Supermarkets and larger club stores constitute nearly 80% of the food retail market and three food retailers (Loblaws, Sobeys and Metro) dominate the sector (USDA FAS 2017). Food sales represent nearly 20% of the entire retail sector in Canada (USDA FAS 2017).

2.4.4.2 Mexico

In Mexico, up to 50% of food retail is estimated as informal and 24% of primary food production is for self-consumption (INEGI 2014b). The informal sector at each stage of the supply chain represents a significant gap in data and one that needs to be better understood to address FLW in the longer term. The informal sector has different challenges and opportunities than the formal one (World Bank 2018, internal document).

2.4.4.3 United States

In the United States, the retail sector is dominated by grocery stores and supermarkets. These are geographically dispersed but are overwhelmingly dominated by a few massive companies. Walmart, Kroger Co., Safeway and Publix together account for nearly 40% of food retail sales in the United States (Bells 2015). Total annual supermarket sales in the United States are nearly US$700 billion, and supermarkets alone employ nearly 5 million Americans (Food Marketing Institute 2018).

In the United States, cold chain infrastructure is generally adequate and there is a plethora of transportation options for food products. Thanks to this, FLW generation during distribution is relatively low. That said, inaccurate forecasting and surplus products still contribute to FLW in many cases.

Because of the centralized nature of the retail sector, retailers in the United States have a large impact on FLW generation in the rest of the food supply chain. For example, quality standards and general business operations across the food supply chain are highly influenced by the most dominant companies in this sector. This means not only that inefficiencies in this stage of the supply chain can affect losses in other stages, but also that changes in this sector can have far-reaching effects on FLW generation across the entire supply chain.

2.4.5 Food Service and Institutions

The food service sector includes all varieties of institutions that serve prepared food intended for final consumption. In this sector, food products are taken from their raw, processed or manufactured state and prepared in-house. The final product is most often sold in single portions, though certain business models serve food in larger portions.

Examples of organizations within this sector are restaurants, caterers, hotels or venues that prepare or serve food, street vendors, convenience stores with prepared food or cafeterias, as well as public institutions such as prisons and hospitals.

Within this sector, there is an important distinction to be made between pre-consumer and post-consumer waste. Pre-consumer waste is any waste that occurs before the food is on the customer's plate, and post-consumer waste is any waste that occurs after that point. Some in the sector may refer to this as "back of house" and "front of house," respectively.

Root causes of FLW generation in food service tend to apply to most market segments and are not geographically specific. These root causes include inappropriate portion sizes, inability to manage demand fluctuations, preparation mistakes, rigid management, and improper handling and storage (Uzea et al. 2014).

The following is a non-exhaustive but illustrative list of additional approaches to reduce FLW generation within food service:

- Working with actors upstream in the food supply chain to increase the share of second-grade products that are accepted and valorized to some point;
- Improving cold chain management and infrastructure to prevent spoilage or degradation during storage and transport;
- Reducing overproduction of under-consumed products or shifting from production models that routinely overproduce food (e.g., buffets); and
- Rethinking purchasing models and promotional strategies to maintain freshness and reduce shrink.

2.4.5.1 Canada

The Canadian food service industry continues to grow along international trends, and Canadian food service sales reached C$61.1 billion in 2015 (Maze 2018; Agriculture and Agri-Food Canada 2017). Although Canada is home to several franchises and many of the same fast-food-style restaurants as the United States, a greater proportion of the Canadian food service industry is made up of small and medium-sized enterprises.

2.4.5.2 Mexico

Mexico has the highest proportion of local, independent businesses in the food service industry of all North American countries. These smaller businesses account for nearly all the food service establishments in the country and more than two-thirds of the sales in the sector; they tend to have much lower levels of FLW than larger restaurants or those found in Canada or the United States. This is largely because of frequent customers, unchanging menus and adequate portion sizing, which allow for highly accurate forecasting. These establishments may have less cold chain storage infrastructure than their larger counterparts, but regular cycles of purchasing and sales prevent this from generating significant amounts of FLW (Alatriste Mendoza 2014).

The hospitality and food service sector is rapidly growing in Mexico, with some estimates as high as 4.3% per year. Given its growth the sector could have an increasing impact on FLW. Often there is very limited measurement and data on FLW, and losses are often regarded or perceived as “the cost of doing business” (World Bank 2018, internal document).

Establishments dedicated to the preparation of food and beverages in 2013 generated P$177.145 billion in 2013, representing 1.1% of the national GDP (INEGI 2014c).

2.4.5.3 United States

In the United States, there is a continued and steady growth in the food service industry. American consumers continue to increase the proportion of food they eat away from home; the average American now spends more on food consumed outside the home than on food consumed at home. The growth in this sector has been ongoing for several years but is currently most marked in the “fast casual” segment of the market, which emphasizes quick, customizable, healthy options at a low price (Maze 2018).

The food service industry in the United States is diverse, ranging from multinational companies such as McDonald’s and Burger King to hotels such as Holiday Inn and even sports stadiums. Fast-food restaurants make up the largest share of any restaurant market segment.

2.4.6 Household

Within the food supply chain, the household sector encompasses all food preparation and consumption in the home. Although it is uncommon for an individual household to track its food waste, governmental or nongovernmental organizations may want to monitor household generation of FLW. For purposes of this report and the accompanying practical guide, this sector includes only food consumed in the home. Food consumed away from home would fall under the food service stage in the food supply chain.

Household FLW can be caused by any number of factors, including lack of meal planning, preparation mistakes, lack of proper storage infrastructure or practices, trimming for consistency, misshapen products, spillage during handling, poor portion control, contamination, over preparing, over purchasing, or food safety and food quality labelling concerns.

2.4.6.1 Canada

Canada has a population of 37 million people, most of whom live near the southern national border (Gatehouse 2018). In contrast to the dense urban centers along the southern border, northern populations are relatively sparse and dispersed.

Canadians waste an estimated 170 kilograms of food per capita per year at the consumer level (CEC 2017b). This estimate includes both food eaten at home and away from home. This stage in the food supply chain accounts for more FLW than any other in Canada.

2.4.6.2 Mexico

Mexico has a population of over 123 million people, the vast majority of whom (78%) live in urban areas (INEGI 2014a). Many Mexican cities act as large metropolitan centers beyond their borders. Mexico City, for example, has nearly 9 million citizens in Mexico City proper, yet more than 21 million are in the city's metropolitan area. This makes Mexico City the most populous metropolitan area in the Western Hemisphere (World Population Review 2017). For comparison, the entire rural population of Mexico is around 27 million.

Mexicans waste an estimated 37 kilograms of food per capita per year at the consumer level (CEC 2017b). This estimate includes food eaten at home and away from home. This stage in the food supply chain accounts for less FLW than any other in Mexico.

2.4.6.3 United States

The United States is the most populous North American country, with 327 million people. More than half of this population is in suburban areas, followed by urban populations and rural populations (Pew Research Center 2018).

Americans waste an estimated 188 kilograms of food per capita per year at the consumer level (CEC 2017b). This estimate includes food eaten at home and away from home at food service establishments (e.g., restaurants, cafeterias). This stage in the food supply chain accounts for more FLW than any other in the United States.

2.4.7 Whole Supply Chain

A whole supply chain approach encompasses all stages in the food supply chain. This includes all activities and destinations from production to final consumption, recovery, recycling or, ultimately, disposal. An example user of this approach would be a national government. A useful application of this approach would be to analyze flows of specific food products or food categories across the entire food supply chain. Such an approach can provide insights into material flows, food availability, environmental impact, food waste hot spots and opportunities for prevention, disposal methods, production and consumption trends, and so on. A user can also vary the working definition of FLW (i.e., adjust the scope of their analysis), and in doing so can focus the analysis on specific aspects of the food supply chain.

FLW can be generated for a variety of reasons throughout the supply chain. The user is recommended to review the relevant sector-specific module in the practical guide for details at each stage. Although a whole supply chain approach is useful for many reasons, specific institutions will follow different types of measurement methodologies based on the goals of their respective organization and stage in the food supply chain.

2.5 Summary: Definitions, Frameworks and Rationale

This chapter has summarized a range of information that underpins quantification of FLW. The key points are:

- It is important that an organization understand why it is quantifying FLW. There is a range of reasons for an organization to quantify FLW (e.g., tracking against targets, evaluating solutions) and each has different requirements for successful quantification.
- Organizations need to be clear on the objectives they would like to achieve (e.g., minimizing environmental impact, sustainable management of materials). An understanding and articulation of underlying objectives allows the organization to set a clear and appropriate FLW definition that aligns with these objectives. In addition, it allows the design of the FLW quantification to support its aims.
- Measurement of FLW is usually insufficient by itself to take effective action. Supplementary information is required, gathered through other techniques (e.g., observations, interviews, and site visits). This additional information can be useful for understanding the root causes, embedded costs and context of the issue and creating potential solutions. These additional techniques are described in Chapter 3.
- Preventing food from being wasted (i.e., source reduction) usually yields the greatest financial gain for an individual business or household. In addition, prevention usually has a much greater environmental benefit compared with diversion from landfill to a treatment destination (e.g., anaerobic digestion).

3 Quantification of FLW and Food Surplus

This chapter describes a range of methods for quantifying the amounts of food loss and waste (FLW) and food surplus. A description of each method is provided alongside descriptions of their application in Canada, Mexico and the United States, as well as selected examples from other countries around the world.

As outlined in Section 2.1, it is often useful to quantify not only FLW and food surplus, but also the types of food involved and the reasons for the waste. With this additional information, root causes can be identified and solutions created to prevent or divert that food waste. This chapter also notes the degree to which each of these methods can provide this additional information. This means that some of the approaches discussed, especially those in Section 3.8, go beyond simple quantification; they are processes to bring about change, with quantification as one step within each process.

Examples of each method are given in a range of situations across the supply chain, with a particular focus on Canada, Mexico and the United States. In addition, references are given to documents that provide more background on the quantification methods and on how to put them into operation. Of note is the *Food Loss and Waste Accounting and Reporting Standard*, referred to here as the *FLW Standard* (FLW Protocol 2016), which contains details of these methods and how to apply them. The reader in search of a high level of detail should consult these documents. To facilitate straightforward cross-referencing, the sections in this chapter are broadly aligned with those in the *FLW Standard*. Other useful documents in this space include the *Food Waste Quantification Manual to Monitor Food Waste Amounts and Progression* (FUSIONS 2016), which takes the methods in the *FLW Standard* and applies them to each sector in the supply chain for governments quantifying their country's FLW.

Table 1 provides an overview of the methods included in this chapter and how they are grouped.

Table 1: Quantification Methods Described in this Chapter

Section	Methods and Sub-Methods Included
Direct weighing/counting/assessing volume	Weighing samples of unharvested produce in field
	Sampling FLW in processing and manufacturing as it arises
	Scanning FLW and food surplus in retail
	Smart bins in hospitality/food service settings
	Use of FLW caddies in the home
Waste composition analysis (WCA)	Food-focused WCA studies
	WCA focusing on all materials in a waste stream
Records	Use of records (e.g., waste transfer receipts, records of chemical oxygen demand, payments to sewerage companies and warehouse records) to quantify FLW or food surplus
Diaries	Diaries for recording FLW
Questionnaire surveys	Questionnaires to collate existing data
	Questionnaires as a quantification tool
Inference by calculation	Apply loss and waste factors to food flows
	Mass balances

Section	Methods and Sub-Methods Included
	Synthesis methods
Sewer waste	Includes chemical oxygen demand, biological oxygen demand, total suspended solids, total dissolved solids and total organic content

3.1 Direct Weighing, Counting or Assessing Volume

Direct weighing, counting, or assessing volume involves the measurement of a material flow containing only food without the need for sorting first. For mixed material flows, containing food and nonfood items, see Section 3.2 on waste composition analysis (WCA). For the measurement to take place, direct access to the material flow is required. For this reason, it is usually applied by businesses on their own food flows, most commonly in primary production (e.g., on a farm) and inside processing, manufacturing, distribution and retail facilities. In addition, academics and other third parties occasionally use these methods as parts of research studies.

The material for measurement can be intercepted at various points along its journey. Examples in this section include weighing taking place in the field, direct measurement within a factory, scanning within a retailer and weighing in the home.

As with WCA, this method can provide information on the total amount of FLW and food surplus and its variation over time. However, it does not by itself provide much information on why food is lost or wasted or becomes surplus. For this reason, it is often used in combination with other methods that can develop this knowledge (e.g., interviews, diaries and site visits).

Direct measurement can be part of an ongoing monitoring system (e.g., as part of a facility's system for key performance indicators) or can be undertaken less frequently, for example, as discrete, time-limited measurements to inform the development of a business case. The methods have been tailored within different supply chain sectors, as outlined below.

More details of direct measurement can be found in the annex on quantification methods of the *FLW Standard* (Sections 1–3).

3.1.1 Examples of Direct Measurement

Direct measurement has been used across the food supply chain. A range of examples is given below to illustrate this breadth. All supply chain stages except distribution and wholesale are represented.

Primary Production

There is a range of approaches based on direct measurement that have been applied to primary production. These have been applied to the many processes that can occur on a farm to track the material flows, including those that represent repurposing crops to feed animals, to provide nutrients to soil (e.g., food being composted), or to other uses that otherwise do not achieve the crops' full financial potential.

An example of this is described in a toolkit to support farmers to assess the amount of marketable produce remaining in their field to help prevent in-field losses of crops (Johnson 2018; Johnson et al. 2018). This involves a one-time assessment of the crop found within a sample area of a field, involving six steps:

1. Note the row spacing and the acreage in the field. Gather equipment.
2. Mark rows randomly in the field.
3. Harvest rows.

4. Sort samples into categories.
5. Weigh and record samples in each category.
6. Calculate an estimate of the potential in the field.

The toolkit suggests three categories for sorting: marketable (e.g., high-quality appearance), edible (e.g., cannot meet highest buying specification but still edible) and inedible. The categories can be adapted to further sort the inedible items according to the reasons why they are inedible (e.g., insect damage, disease, decay, over-maturity). This additional stage can help farmers to identify the root causes leading to items being unsuitable for harvest and to find a possible market in which to sell them.

In primary production in the United Kingdom, strawberry and lettuce waste was assessed using a mix of methods (web surveys, interviews and on-farm data collection) to understand the amounts, types and reasons for waste (WRAP 2017). The study found that the estimate of lettuce waste derived from the interviews (17%) was much lower than that estimated from data collection (33%). The authors suggested that farmers commonly underestimate the level of their lettuce waste and that on-farm data collection (i.e., direct measurement) is required for accurate estimates.

Currently, the Stewardship Index for Specialty Crops and the World Wildlife Fund are developing a food loss metric for growers to track and report the amount of food grown to maturity but not used (McBride 2018).

Table 2. Factors to Consider When Using Direct Measurement for FLW Quantification in Primary Production

Strengths	Limitations/Points to Consider
• **Gives accurate estimates of amounts and types of FLW** • **Is adaptable to support a change program** • **Estimates can be used to guide financial decisions**	• Requires time to implement, often at busy times of the year for farmers (e.g., harvest) • Financial cost is associated with method • Access to field/farm facilities is required • Can be used in combination with other methods to obtain reasons for FLW

Manufacturing and Processing

The direct measurement of material flows in manufacturing and processing facilities is part of many toolkits aimed at identifying and tackling FLW. For instance, the Provision Coalition's Food Loss and Waste toolkit (based on Enviro-Stewards' source reduction-based approach, described in greater detail in Section 3.8) suggests, among other methods, direct measurement of FLW in manufacturing and processing facilities. The exact details of the measurement should be tailored to the FLW that is being generated and to where it is being generated. It usually involves the food that is being lost or wasted being diverted to containers (e.g., buckets) from which it can be weighed. Food is collected for a known amount of time (e.g., one eight-hour shift) and the amount is then scaled up to provide an approximate estimate of the amount for a week, month or year. More accurate estimates would require repeated sampling designed to account for fluctuations over time (e.g., seasonality).

The tool is designed for manufacturers and processors but could be used by other sectors. Although designed for Canadian users, most of the tool would work with information from Mexico and the United States. The financial and nutritional calculations would be accurate, but some of the environmental information calculated uses factors (e.g., carbon factors) that are specific to Canadian provinces so would not be entirely accurate for other countries.

Table 3. Factors to Consider When Using Direct Measurement for FLW Quantification in Processing and Manufacturing

Strengths	Limitations/Points to Consider
• **Has high level of accuracy (for weight and other impacts that are estimated using weight— embedded energy, water, product value, and so on)** • **Can provide granular data to support change programs** • **Data can be used to estimate range of metrics (e.g., financial, environmental) to support business case development** • **Can be operated consistently across many sites (e.g., factories, distribution centers) and data combined**	• Cost of measurement will vary, but can be relatively cost effective • Could lead to change in behavior of staff undertaking measurement, making baseline measurement less accurate • Can be used in combination with other methods to obtain reasons for FLW

Distribution and Wholesale

No examples of direct measurement were found for this sector. However, methods described under the description of the retail sector could be implemented in the distribution and wholesale sector.

Retail

The scanning of packaged food products is an example of direct measurement that is applied in a range of sectors, especially the formal retail sector. When items leave the retailer's premises for reasons other than being sold (e.g., landfill, donation), they are scanned, and this information is integrated into a database. This database can then be used to quantify the amounts and types of food going to different destinations. It can be used to estimate the value of lost sales and can provide a good starting point for prioritizing action for preventing food from being wasted. An example of this being used across North America is Spoiler Alert,[7] which helps "food manufacturers, wholesale distributors, and grocery retailers manage unsold inventory more effectively" by identifying where unsold food is currently going and facilitates solutions to manage this surplus (e.g., food donations to food banks or discounted sales).

Items in the categories of fresh produce, bakery and delicatessen are often challenging to capture because they are often not consistently scanned. Experts convened for this project highlighted this as one of the biggest challenges when working with retailers to understand how much FLW they produce and the types of food contained within the FLW.

[7] A Boston-based company; see https://www.spoileralert.com.

Table 4. Factors to Consider When Using Scanning for FLW Quantification in Retail

Strengths	Limitations / Points to Consider
• **Has high level of accuracy for most products** • **Provides highly granular data to support change programs** • **Approach can be used to estimate range of metrics (e.g., financial, environmental) to support business case development** • **Can be operated across many sites (e.g., stores, distribution centers) and data can be compared or combined**	• Requires products to be packaged with bar codes • Additional solution may be required for unpackaged food (e.g., fruit and vegetables sold loose) • Initial cost to develop system can be expensive but can be based on existing sales data system • Requires changes in procedures to ensure wasted or lost or surplus items are scanned

Hospitality and Food Service

The use of smart bins is relatively common in food service kitchens. The smart bin weighs items as they are placed in the bin. The user can enter details of the item being added so that the type of food being wasted and the reason it is wasted can be recorded. This information is collated in a database that can be interrogated to provide information for preventing FLW (or diverting it up the waste hierarchy). It can also be linked to procurement systems to provide financial information. Smart bins can be deployed as a one-time project to facilitate change or provide ongoing monitoring for continuous improvement and measurement of performance data. Examples include LeanPath[8] (based in the United States), Phood Solutions[9] (based in the United States) and Winnow Solutions[10] (based in the United Kingdom). Other companies in this sector simply use buckets that are weighed daily (Sodexo, no date).

Table 5. Factors to Consider When Using Smart Bins

Strengths	Limitations / Points to Consider
• **Provides highly granular data to support change programs** • **Can be used to estimate range of metrics (e.g., financial, environmental) to support business case development** • **Can be operated across many kitchens and data combined**	• Measurement has the potential to change behavior (e.g., stimulate FLW prevention activities), so accurate measurement of baseline may be difficult • Financial cost and staff time required for installing and using smart bins, and analyzing data • Difficult to apply to FLW going down the sewer

[8] See www.leanpath.com/.

[9] See https://phoodsolutions.com/index.html.

[10] See www.winnowsolutions.com/.

Hospitality and Food Service: Plate Weighing

Plate weighing is a method for measuring plate leftovers in hospitality and food service settings. This has frequently been used in schools as well as in a range of other settings. It usually involves two direct measurements: of a sample of trays containing the food directly after serving to establish the average amount being served and of a sample of trays after the diners have eaten, containing the plate leftovers. The amount of plate waste is usually expressed as a percentage of these two quantities (Buzby and Guthrie 2002). Recently there have been some advances in this area using digital photography (see Diaries, Section 3.4, for more details).

Table 6. Factors to Consider When Using Plate Weighing

Strengths	Limitations/Points to Consider
• **Is a well-researched and relatively accurate method** • **Can provide detailed information on the types of food wasted or lost (if recorded)**	• Only covers plate waste; does not include preparation (i.e., back-of-house) waste • Relatively expensive to undertake • Can be used in combination with other methods to obtain reasons for wasting food

Households

To quantify food waste in the home, collecting food in a caddy (or other container) and then weighing it has been developed as part of several projects (e.g., *Food: Too Good to Waste* [US EPA 2016a], Kitchen Canny in Scotland, United Kingdom [Changeworks, no date]). No examples of similar pilots/studies with household caddies were found for Canada or Mexico. In the EPA example, food waste was collected in a measurement bag or bucket. This was deployed as part of a month-long challenge aimed at preventing food waste. Some caddy measurement schemes allow liquid waste (e.g., from drinks) to be included, but many do not include this.

This caddy approach was assessed against a range of other in-home measurement methods (diaries, photo diaries, questionnaires) in research led by Wageningen University (van Herpen et al. 2016). The caddies provided a similar estimate of FLW compared with the diaries and photo diaries. Given that diaries are known to underestimate FLW, it was concluded that caddies are also likely to underestimate FLW, to a similar degree. It is not yet known if the degree of underestimation varies over time or over the course of an intervention.

Table 7. Factors to Consider When Using Household Caddies

Strengths	Limitations / Points to Consider
• **Is a simple, relatively cheap method to implement** • **Approach can be adapted to obtain information on a small number of categories (e.g., wasted food, inedible parts associated with food)** • **Potentially can be applied to all destinations/discard routes from a home**	• Is likely to underestimate amounts of food wasted • Little information on the types and reasons for wasting food (must be used in combination with other methods) • In hot conditions, there is the potential for moisture to be lost, affecting FLW estimates

Whole Supply Chain

Across a range of sectors, direct measurement is frequently applied to food-only waste streams (e.g., waste streams destined for anaerobic digestion or composting). This is either undertaken by the company from which the waste is being removed (e.g., the retailer), or by the contractor removing the waste. When this information is obtained by those attempting to tackle FLW issues, it can provide the scale of the problem in terms of tonnage. However, it does not usually supply much information on the types of food waste or the reasons why it was generated. Therefore, this type of information usually must be supplemented with other information (e.g., from site visits, interviews or observations, to ensure that the root causes are being tackled).

Table 8. Factors to Consider When Measuring Food-Only Waste Streams

Strengths	Limitations/Points to Consider
• **Is relatively cost effective, especially if waste management company already ollects data (see Section 3.3)** • **If data supplied regularly, can help inform a performance indicator**	• Is limited to food-only waste streams • Does not usually provide information on the types and reasons of wasted food; does not provide information on why food items have been wasted (need to combine with other methods) • In hot conditions, moisture can be lost, affecting FLW estimates

3.1.2 Summary: Direct Measurement

Direct measurement encompasses a range of methods that involve counting, weighing or measuring the volume of all FLW and food surplus in question, or a sample of this total. As there is such a wide range of methods, some using electronic systems (e.g., smart bins and scanning systems) and others using lower-tech solutions (e.g., a collecting vessel and some scales), there are fewer common elements to summarize than for other sections in this chapter.

However, methods using direct measurement are usually used by organizations with access to the FLW being quantified. This has the advantage that the wasted items can often be placed on scales and weighed or its quantity determined in another relatively accurate way. One of the key challenges in obtaining accurate information is to ensure that any sampling required is undertaken appropriately. By ensuring that the sample is representative with regard to time (e.g., within a day, across seasons) and space (e.g., sampling within fields, between facilities), data from a relatively small number of measurements can be extrapolated more widely and the uncertainty in the data can be quantified.

Direct methods are applied to FLW that has not been mixed with nonfood material, so it is less expensive than methods that require sorting of the material before weighing (e.g., waste composition analysis).

Table 9. Summary of Direct Measurement Methods as Applied to Different Sectors

Sector	Coverage of Method

Sector	Coverage of Method
Primary production	Pre-harvest and post-harvest losses usually measured by sampling (i.e., not measuring all FLW)
Processing and manufacturing	Applied to intercepted loss/waste emanating from a process Also used to quantify food-only waste streams
Wholesale and distribution	Scanning used to track material flows of packaged products Weighing used for food-only waste streams
Retail	Scanning used to track material flows of packaged products Weighing used for food-only waste streams
Food service/institutions/out-of-home consumption	Smart bins are regularly used in kitchens Plate-waste studies have well-developed protocols Weighing is used for food-only waste streams
Household	Caddy-based methods are used within food-waste prevention initiatives

Conclusion: Direct Measurement

Direct measurement encompasses a suite of different approaches that have been used across the supply chain. It requires physical access to the food flow being quantified and the food must be separate from nonfood material (otherwise sorting is required). This method can form an important part of a change management process, and toolkits already exist for this purpose.

3.2 Waste Composition Analysis

Waste composition analysis is a well-established method that involves physically separating, weighing and categorizing waste. There are many examples of the method being used to quantify FLW, generally where the food is found in mixed waste streams (e.g., mixed commercial or municipal/residual waste streams). WCA goes by many names, including “waste characterization study,” “waste sort,” “waste audit” and “bin dig.” It has been used in all sectors of the supply chain except primary production.

WCA can be used to determine the total amount of food waste and can also be used to quantify the amounts of different types of food. For example, it can be used to differentiate the wasted food (i.e., the edible parts) from the wasted nonfood (the inedible parts). It has been used to quantify the waste associated with different food categories—fruits, vegetables, baked goods and meal waste, for example. In the following discussion, a distinction is made between:

- WCAs that focus on food, characterizing food groups/types, and
- WCAs that examine all materials found, with food being one category among many.

The information derived from a WCA study is frequently used to monitor a state's or a province's solid-waste diversion goals, assess the impact of landfill bans, and provide information to estimate the environmental outcomes associated with FLW. More details on WCA can be found in Chapter 4 of the annex on quantification methods of the *FLW Standard*.

3.2.1 Examples of Waste Composition Analysis

There are a variety of ways of using WCA to quantify FLW. The examples below illustrate this variety, with many of the methods tailored to help support solutions for tackling these issues.

Food-focused Studies

Food-focused WCA studies are designed to quantify FLW in waste streams. To build understanding of the types of food discarded, such studies often subdivide FLW, sometimes quantifying more than 100 categories and subcategories of FLW. Some WCA studies also provide information on the other materials found in the waste streams, but many do not.

One of the best-documented examples of this method in North America is a 2017 study by the Natural Resources Defense Council (NRDC), in which WCAs (or "bin digs," as they were termed in that report) were used along with surveys and diaries to quantify and understand wasted food in three US cities (NRDC 2017). The WCA method involved collecting the trash from each participating household around the time that they were completing a food-waste diary, removing it to an offsite location and sorting into material categories. The food was sorted into 10 categories, one of which represented inedible parts associated with food. Eight others represented food groups for wasted food (e.g., edible parts). The final category was for unidentifiable material. The items classified as edible were further classified as either typically edible or questionably edible, to reflect the complexities of defining edibility on the basis of cultural preferences and other factors.

These two studies are recent examples of using WCA alongside other research methods to increase understanding of wasted food and to support campaigns and other interventions to tackle the issue. The study that is widely cited as the first of this kind is *The Food We Waste* (WRAP 2008), developed in the United Kingdom. This has subsequently been updated with an improved methodology, published as *Household Food and Drink Waste in the UK 2012* (WRAP 2013a). This study used detailed WCA to estimate the amounts and types of food thrown away from UK households. The level of detail surpassed previous studies, with information on not just a single type of food (e.g., apples), but on parts of the item in question (e.g., how many apple cores, how many whole apples). This was supplemented with food diaries and questionnaires to help uncover the reasons for this wasted food and the characteristics of households wasting specific foods. Indeed, so much information was produced that two further reports were produced to fully exploit these data sets (WRAP 2014a and WRAP 2014b). This information has been invaluable to the development of WRAP's public-facing food waste prevention campaign, Love Food Hate Waste,[11] and the Courtauld Commitment (a voluntary agreement focused on food waste).[12]

Many similar studies around the world have adapted this approach. For instance, some combination of diaries, surveys and WCA has been used in Metro Vancouver, Canada (Cech 2015; few details published); Australia (e.g., Sustainability Victoria 2014); New Zealand (WasteMinz 2015), Saudi

[11] See www.lovefoodhatewaste.com.

[12] See www.wrap.org.uk/category/initiatives/courtauld-commitment.

Arabia (unpublished) and Israel (Elimelech et al. 2018). No detailed waste composition studies have been found for Mexico.

In the unpublished Saudi Arabian study, waste was collected more frequently (e.g., daily) compared with the frequency in many other countries' studies using WCA. This overcame the problem of food decomposing in hot weather. It also allowed analysis investigating the variation in waste throughout the week; but it also increased the cost of collecting and sorting waste from households. Consequently, the waste from households was only collected for four days, a period shorter than most studies.

Elimelech et al. (2018) presented a variant of WCA in which households presented their waste daily for collection by the researchers before it was sorted and weighed. The study involved 192 households and classified the FLW into avoidable and unavoidable.

Waste compositional analysis has not just been applied to household food waste. Studies have also focused on the food service sector. For example, WRAP (2013c) sampled residual waste streams (destined for landfill) from samples of restaurants, "quick-service restaurants" (i.e., fast-food outlets), hotels and cafes.

Table 10. Factors to Consider When Using a Food-Focused Waste Composition Analysis for FLW Quantification

Strengths	Limitations/Points to Consider
• **Can provide relatively accurate data on the total amount of FLW within given waste streams** • **Can also provide detailed information: types of food wasted, whether it is packaged, whether it was a whole or part of an item, and so on** • **Detailed information can be used to estimate cost, environmental impacts and nutritional content of FLW** • **Can link information to households in study, allow demographic analysis, and correlation studies with stated behaviors, attitudes, and so on**	• Cannot be applied to all destinations (e.g., FLW in sewer waste) • Detailed studies are likely to be expensive to perform—for detailed information, relatively large sample sizes are required • Does not provide much information on why food items have been wasted • Can be affected by moisture losses in hot conditions

WCA Focusing on All Materials in Waste Stream

In contrast to food-focused studies, there are also many studies that focus on quantifying all materials in a given waste stream. Often food is one of these categories, although sometimes it is not separately quantified and forms part of "organic waste." Sometimes FLW is subdivided into a small number of categories (e.g., edible parts, inedible parts), but usually these have much less detail than WCA studies that are focused on food.

In Canada, Statistics Canada collects data every two years on waste disposed and diverted for both residential and non-residential waste (Statistics Canada 2018a, 2018b). The residential data by type will have originally been obtained by WCA. These data sets primarily support waste management analyses but may be leveraged to create national data sets on food waste.

From 2009 to 2012, the Government of Mexico launched a coordinated program of waste prevention and management under the National Program for Prevention and Management of Solid Waste

(*Programa Nacional para la Prevención y Gestión Integral de los Residuos)* (Semarnat 2008). This was designed to flow through the devolved levels of government, with state programs for the prevention and comprehensive management of waste (*Programas Estatales para la Prevención y Gestión Integral de Residuos*) and municipal programs for the prevention and comprehensive management of waste (*Programas Municipales Para la Prevención y Gestión Integral de Residuos*). There are also intermunicipality programs for the prevention and comprehensive management of waste (*Programas Intermunicipales de Prevención y Gestión Integral de Residuos*). Using the Framework of National Information for the Comprehensive Management of Waste (*Sistema de Información Nacional para la Gestión Integral de los Residuos*), the programs were intended to implement a systematic approach to waste management across Mexico.

Under this program, the states and municipalities should have analyzed three waste streams: urban solid waste, special-handling waste (e.g., business waste) and hazardous waste. These analyses vary by state and municipality but there are some that have conducted and published results from WCA. A review of available online sources shows nine state-level studies and 20 municipal-level studies conducted from 2009–2016 that included waste composition and reported a separate food fraction. Others included WCA but stopped at the level of organic waste and did not include a subfraction for food.

The different studies conducted varied in their sampling locations and methods. Some studies sampled at the point of generation (e.g., at the household) and others after collection (e.g., at a waste transfer station). Some studies explicitly mention nationally accepted standards, for example, NMX-AA-022 Quantification of Subproducts (Cuantificación de Subproductos); others provide little information on their methodology.

Despite the intent that the program be coordinated and countrywide, the different delegated authorities are acting on different timescales and with different levels of investment in this project. For example, Jalisco is the only state to publish a recent study as part of its plan covering the period 2016–2022; all the other available published reports from state programs for the prevention and comprehensive management of waste are approaching 10 years old.

Other examples of WCA in Mexico are discussed in a CEC report on characterization and management of FLW (CEC 2017b). The report includes city-based WCAs conducted largely by (or in collaboration with) academia; input into the landfill gas model for Mexico (Stege and Davila 2009); and a WCA conducted for the 2013 Mexico Low Emissions Development Program for the Central de Abasto of the federal district (Romero 2013). These examples do not specifically fall under the national, state and municipal programs described above.

There are other examples of WCA focusing on all materials that can be used to inform estimates of food waste. Examples include Metro Vancouver's waste composition monitoring program (Cech 2015), Oregon's Solid Waste Characterization and Composition Study (Department of Environmental Quality 2017), examples from the UK (Defra 2009; Defra 2013), as well as the study by Zero Waste Scotland discussed later in this section (Zero Waste Scotland 2017).

It is more straightforward to combine information from multiple WCAs if they formed part of a standardized program, using similar material categories, definitions, sampling strategies, sorting methods and analysis reporting. It is not impossible to combine data from WCAs that exhibit differences, but more care must be taken and some studies may have to be excluded.

Table 11. Factors to Consider When Using a Waste Composition Analysis Focusing on all Materials in Waste Stream

Strengths	Limitations/Points to Consider

Strengths	Limitations/Points to Consider
• **Can provide relatively accurate data on the total amount of FLW within given waste streams** • **Can be relatively inexpensive where studies or programs already exist** • **Can be replicated to monitor progress**	• Cannot be applied to all destinations (e.g., FLW in sewer waste) • Does not include detailed information on types of food required to estimate accurate cost or impacts of FLW • Does not provide much information on why food items have been wasted • Can be affected by moisture losses in hot conditions

Guidance Documents

Several guidance documents describe how to undertake WCA in a standardized way. These help to ensure that results from multiple WCA studies are comparable. They also allow results from multiple studies to be combined more easily by increasing consistency between studies.

In Mexico, there are a series of national standards on measurement of waste. For food, the relevant standards include:

- NMX-AA-015: method of quartering municipal solid waste (Secretary of Commerce and Industrial Development 1985a)
- NMX-AA-019: determining volumetric weight of municipal solid waste when quartering (Secretary of Commerce and Industrial Development 1985b)
- NMX-AA-021: determining organic waste (Secretary of Commerce and Industrial Development 1985c)
- NMX-AA-022: selection and quantification of waste subproducts, including food (Secretary of Commerce and Industrial Development 1985d)
- NMX-AA-061: determining the generation of municipal solid waste from random sampling (Secretary of Commerce and Industrial Development 1985e)
- NMX-AA-091: terminology (Secretary of Commerce and Industrial Development 1985f)

These standards provide a step-by-step scientific method and calculation approach for each purpose and are linked to each other where appropriate. For example, a method for extracting a sample of waste by quartering is laid out in Standard 15. It is then referred to in Section 5.1 of Standard 22 as the process for obtaining a sample before classifying subproducts. Standard 22 includes a note on the definition of food as a subproduct of waste but it is limited to specifying that waste that could have degraded before sampling should still be included as solid food waste: "Solid food waste should include all easily degradable waste, such as: viscera, appendages or carcasses of animals."

The sampling standard (Standard 61) suggests that a minimum sample of 50 households is required for a population of between 300 and 500 households to achieve a 20% margin of error. This corresponds roughly to Zero Waste Scotland's guidance (see below). That guidance suggests there will be a 15% sampling error for the same sample size.

One of the examples of WCA in Mexico, Semadet Jalisco (2017), states that Standards 19 to 22 (consequently including Standard 15) and Standard 61 were used to calculate the values presented there.

In the United Kingdom, Zero Waste Scotland has produced similar guidance (Zero Waste Scotland 2015) as part of a program of WCA in all municipalities (under local authorities). The guidance aims to ensure consistency between WCAs, allowing the results from the municipalities to be combined to produce national estimates for household waste in Scotland (Zero Waste Scotland 2017).

There are also detailed methodologies for how to undertake more detailed WCAs focused on differentiating different types of food. These include Lebersorger and Schneider (2011), WRAP (2013b), NRDC (2017) and Elimelech et al. (2018).

In addition, there are a few studies that have detailed how to analyze existing data from multiple WCA studies (e.g., from municipalities) to produce an estimate for a wider area (e.g., a country). In some instances, these have combined data from a standardized program of waste compositional analysis (e.g., Van Westerhoven 2013, Hanssen et al. 2013, Zero Waste Scotland 2017).

In other studies, existing WCA data from studies that have not formed part of a standardized program have been combined (e.g., WRAP 2018b). In such situations, steps need to be taken to ensure that differences in WCAs are not influencing the results. Important steps include:

- Rigorous screening of the WCAs and exclusion of studies that do not meet appropriate criteria, such as the material categories used and sampling design;
- Regression-type analysis to determine factors that correlate with amount of food waste; and
- Stratification or weighting of the sample to ensure that, if the sample is not representative of an important factor (i.e., one found to correlate with the amount of food waste), this is corrected for.

This type of synthesis approach is discussed in Section 3.6.

In the United States, the use of data from waste generation studies to determine factors that can be used to calculate the amount of household food waste generated is a variant on the above types of study (EPA 2016c). The EPA's work in this area highlighted that, including material disposed and diverted (e.g., recycled), food waste made up a small share of the all materials. However, when disposal was considered alone, food waste was the largest component.

3.2.2 Summary: Waste Composition Analysis

Waste composition analysis is appropriate for mixed material flows (e.g., waste streams containing both food and nonfood materials). Sorting food-only material flows is not necessary to obtain a quantification of the total; direct weighing can be used instead. However, if the types of food contained within a food-only material flow must be identified, WCA is still an appropriate method.

The main advantage of WCA is that, like direct weighing, it involves a direct measurement of the food loss or waste. It therefore overcomes one of the key challenges associated with recall surveys and diaries: underestimation of the quantity of waste. WCA can be tailored to provide information on the types of food being wasted or lost, which can be invaluable for devising and implementing a program of change.

If deployed by itself, WCA usually only provides a small amount of information about the root causes associated with the food loss and waste. It is usually possible to infer the root causes of loss or waste for only a minority of foods using WCA. To ensure that the root causes of FLW are addressed, WCA usually must be supplemented with other methods (e.g., interviews, site visits, food diaries).

The WCA method requires legal and safe access to the material flow or waste stream. This makes it appropriate for companies to undertake WCA on their own material flows, or for governments to undertake WCA on municipal waste streams. WCA is not appropriate for some waste streams (e.g., material poured down a sewer). In hot climates, WCA may have to be conducted quickly before the food degrades to a degree that makes sorting difficult or hazardous to health.

WCA can be more expensive than other methods and it does require specific expertise to conduct. This may limit the amount of material that can be sampled for a given budget. However, where programs of existing WCAs are undertaken (usually on a range of materials), this information can be used, often at minimal additional cost. If these programs are repeated, this can provide data to track changes over time and monitor targets (e.g., WRAP 2018b).

Food-focused WCAs can provide a wealth of information on types of food waste. This allows other calculations to be performed using this data, including estimating the financial cost, the environmental impact and the nutrients contained within the FLW (see Chapter 4 for examples of WCA data being used for such studies). There is also the potential to link the amounts and types of FLW to household characteristics (e.g., demographics and questionnaire results relating to stated behaviors and attitudes). This allows much deeper understanding of FLW generation and can be useful in creating and targeting solutions.

Table 12. Summary of Waste Composition Analysis as Applied to Different Sectors

Sector	Coverage of Method
Primary production	Rarely applied in this sector as waste tends to be single stream
Processing and manufacturing	Mixed waste streams (e.g., food and nonfood material going to disposal or treatment destinations)
Wholesale and distribution	
Retail	
Food service/institutions/out-of-home consumption	
Household	Applied to mixed municipal or household-only waste streams

Conclusion: Waste Composition Analysis

Given that a range of detailed guidance for waste composition analysis exists, the key challenge for most governments applying WCA to municipal, household or commercial waste is designing a program that is both cost effective and provides the necessary insight to tackle the issue. This involves:

- Determining if existing WCAs be used instead of commissioning new ones;
- Designing an appropriate sampling approach (e.g. sample size, clustering the sample size by collection round);
- Selecting where to intercept waste for the WCA;
- Deciding on the level of detail required (e.g., only determining the total amount of food in a waste stream, or also quantifying the types of food); and
- Determining if other research methods need to be included to obtain the necessary information to act (e.g., to understand why food is wasted).

3.3 Records

Records are data, often collected for other purposes, that can be used to quantify food loss, waste or surplus. Examples include waste transfer receipts and warehouse records. This method has the potential to be used to quantify FLW for all stages of the supply chain.

Records can be used as part of other approaches. For instance, a mass balance can be undertaken using records relating to the receipt of goods at a facility (e.g., ingredients purchased) and the outgoing products sold from the same facility. They can also inform modeling approaches (see Section 3.6).

Using existing information to quantify FLW often costs less than undertaking new measurements. The accuracy of the data within the records depends greatly on how the information was measured, estimated or inferred. It also depends on the coverage. In some situations, where records are based on measurements and have high coverage of the material stream in question, they may be more accurate than other alternative methods. Conversely, if the records only cover a small fraction of the waste in question and are estimated using a range of assumptions, then they may well be weaker than alternatives.

It may be difficult to assess the accuracy of records in cases where the method used to generate the data is not clear. If records are to be used to quantify FLW or food surplus, the method used to obtain the data in the records should be understood, so that the accuracy can be determined.

As with other methods, guidance on using records can be found in the Chapter 5 of the annex to the *FLW Standard*.

3.3.1 Examples of Records

There are only a few examples of records being used in the public domain. The previously mentioned Provision Coalition Food Loss and Waste toolkit asks the user to input waste management records as one way of estimating FLW from manufacturing facilities. It also asks for information from utility payments for electricity, natural gas and water. This latter information is used to estimate the amount of these resources that becomes embedded in the food within the facility (and is therefore wasted if the food becomes waste).

Table 13. Factors to Consider When Using Records for FLW Quantification

Strengths	Limitations / Points to Consider
• **Relatively cost effective, as records have already been gathered for other purposes** • **Can provide high coverage of material flow to quantify** • **Suitable for initial investigation into food waste to help build internal business case, and can continue as supplement to other quantification methods into the future**	• Accuracy depends on method used for quantification • May be hard to obtain a method for quantification depending on the type of record used • May not have the desired granularity of data (e.g., types of wasted food) • Unlikely to include information on root causes (i.e., reasons why food is thrown away)

3.3.2 Summary: Records

The use of existing information (i.e., records) to quantify FLW is one of the most cost-effective methods and therefore should be one of the first avenues explored. It requires appropriate records being available, accessible and well understood by the person using them.

Businesses are most likely to benefit from using records as there are likely to be fewer barriers to them obtaining their own records, in comparison to a third party obtaining them. Despite the potential benefits of this method, few examples were found in the literature or online.

Table 14. Summary of Records as Applied to Different Sectors

Sector	Coverage of Method
Primary production	Farmers may keep records of some post-harvest losses
Processing and manufacturing	Records relating to waste management can be used to estimate FLW
Wholesale and distribution	
Retail	
Food service/institutions/out-of-home consumption	
Household	No examples found

Conclusion: Records

Although this is a cost-effective method for quantifying FLW and food surplus, few examples exist in the public domain. The success (or otherwise) of the method rests on sharing of information within an organization or between organizations. The information also needs to be appropriate (i.e., sufficiently accurate and available at a frequency that is useful and in a timely manner). Clear communication of how the data was measured and what it covers is also important.

3.4 Diaries

In this context, diaries involve a person or group of people keeping a log of FLW or food surplus. In addition to quantities of FLW, a diary can be used to capture other information, such as the type of food involved, its destination and why it became wasted, lost or surplus. For a diary method to be used, the organization needs not have direct access itself to the FLW or food surplus, so long as the diary participants have this access. The technique has been widely used in the home, as well as examples being used in other settings, such as commercial kitchens.

As highlighted by the examples below, the item recorded in the diary can be quantified in a range of ways: the record could be a weight (with scales sometimes provided to diary participants), counts (e.g., eight bananas), volume-based measurement (e.g., using measuring cups) or an assessment of volume (e.g., a handful of grapes). Furthermore, diaries can be paper-based, recorded through a webpage or an app, or photographic.

Two important factors could lead to inaccuracies (i.e., biases) in the estimates of food loss and waste from diary-based methods:

- **Unrecorded instances of FLW:** diary participants may forget to enter an instance of FLW into the diary or choose not to include it. This could happen to a greater extent where households have more than one occupant and the main diary keeper is unaware of some instances of FLW.
- **Behavioral reactivity:** diarists react to the amount of food they discard by changing their behaviors during the diary-collection period (usually to reduce the amount of FLW they generate).

For both factors, social desirability bias may play an important role (i.e., diarists fill in the diary or modify their behavior in a way they perceive is socially desirable). This may involve choosing to omit certain items, so it appears that they waste less food, or leaning toward citing particular reasons that have less guilt associated with them (e.g., the item was an inedible part).

The extent of diary underestimation has been estimated in a few studies. Typically, diaries report around 60% of the food waste, in comparison to the same FLW quantified using waste composition analysis (Høj 2011, WRAP 2013b, NDRC 2017). Further work is required to understand what factors influence the degree of underestimating.

More details of diaries can be found in the annex on quantification methods of the *FLW Standard* (Section 6).

3.4.1 Examples of Diaries

Using diaries to quantify FLW has a long history; a scoping study was performed in three locations within the United States as far back as the 1960s (Adelson et al. 1963). Recent interest in the topic of FLW has led to more comprehensive studies being performed in North America. One of the largest to date was undertaken by NRDC. In this study, described earlier in the section on waste composition analysis, diaries were used along with surveys and "bin digs" to understand FLW in households in three US cities (NRDC 2017). The diary component asked participants to record a range of information about wasted food:

- Date
- Time
- Meal (e.g., breakfast, lunch, dinner)
- Description of food or beverage being discarded
- State of food or beverage at time of discard
- Weight
- Packaging material
- Discard destination
- Loss reason

The diary was paper-based (pre-printed to minimize the time needed for each entry). To assist with the weighing of the wasted food, participants were provided with a digital kitchen scale and two small plastic containers. A short guidebook was provided that included details on how to complete the kitchen diary. Participants were asked only to record details of food wasted in the household. For food wasted outside the household, participants were asked to provide a brief daily narrative. The diary lasted one week.

In this NRDC study, the diaries were used to provide details of the food wasted to increase understanding of the issue and support action. These details included the types of food thrown away, the discard destination, the reasons given for discarding the material and whether the material was wasted food or associated inedible parts. For a quantitative estimate of the amount of food wasted, the diaries were adjusted to account for underreporting, using a factor derived from a comparison of the diaries and the waste composition analysis.

In Oregon (United States), diaries are an important element of the ongoing Oregon's Wasted Food Measurement Study,[13] alongside qualitative interviews, a statewide survey, focused surveys and WCA. More details from this research will be available when this research is published.

Paper-based diaries have also been used in Vancouver, Canada. As was done in the NRDC study, Metro Vancouver used a combination of diaries and "waste tips" (waste composition analysis) to understand the amounts, types and reasons for food waste (Cech 2015). However, few details of this research have been published.

No FLW diaries from Mexico were found during this project.

Further afield, food waste diaries have been successfully deployed in a few countries. In the United Kingdom, WRAP has undertaken several diaries relating to food waste. These have included two

[13] See www.oregon.gov/deq/mm/food/Pages/Wasted-Food-Study.aspx.

kitchen diaries (see WRAP 2013a and WRAP 2013b) that were similar to the NRDC study described above. The key difference was that participants in the WRAP study could provide the quantity of FLW by weight, by volume, as a number of items (e.g., two slices of bread), or by approximate volume (e.g., a handful of rice). This has the advantage that it reduces the burden on diary participants: they should be able to complete the diary more quickly. In theory, this should decrease the effect of some of the biases mentioned above (e.g., unrecorded instances of FLW). It has the disadvantage of decreasing the accuracy of quantification; the use of scales in the NRDC study will ensure quantities recorded are more accurate. To the best of the authors' knowledge, no academic study has been performed to assess the relative magnitude of these two effects.

In addition, WRAP has undertaken diary research focusing on the food and drink disposed to the sewer in the home (WRAP 2009). This research used methods like those described above. It provided diary keepers with a range of items for measuring volume: measuring jugs, cups and spoons. This research exercise demonstrated that the levels of food and drink that were discarded to the sewer and recorded in a sewer-focused diary were much higher than levels measured through other diary research (research where sewer discard was one of a range of destinations being recorded by research participants). Subsequent analysis suggests that the research design was the most likely cause of this discrepancy; the estimate was greatly affected by whether the diary keeper was asked to focus on one destination (e.g., the sewer) or all destinations (see Section 2.3 of WRAP 2013b). This illustrates the main weakness of diary research: bias in estimates.

Additional examples include paper-based diaries deployed in households in Sweden (Williams et al. 2012) and Finland (Silvennoinen, et al. 2014).

An interesting recent development around FLW diaries is the use of photography to quantify food as part of a digital diary. US researchers have developed and tested a new method to record food intake and plate waste (i.e., a subset of FLW in the consumption stages of the supply chain—in the home and out of the home—comprising leftovers on the plate) (Roe et al. 2018). This study involved collecting plate-waste data at the food-item level from 50 adults using the Remote Food Photography Method®. This included consumption within the home and out of the home. The estimates of food intake have been compared with estimates using doubly labeled water (an accurate but expensive method); the two give similar results. This could potentially be used to estimate FLW; however, it is unclear whether testing was done for this.

Table 15. Factors to Consider When Using Diaries for FLW Quantification

Strengths	Limitations/Points to Consider
• **Provides information on the types of food wasted and the reasons behind that waste** • **Can gather data on otherwise difficult to measure material flows (e.g., food waste going down the sewer or at-home composting)**	• Can be relatively expensive, especially if diary participants are given an incentive • Can underestimate the amount of waste because of aspirational biases • Can be coupled with interviews or ethnographic methods to further understand why food gets wasted

3.4.2 Summary: Diaries

Diaries can provide a rich wealth of information, including highly granular information about the amounts and types of FLW, alongside information on why food is thrown away. This is usually the immediate reason given by the diary keeper, but it can often be used to infer some information about the root causes.

Diaries have been deployed most frequently in household settings. They are frequently used in combination with other methods to give a more complete picture of FLW in the home. The information coming from these studies has been used to develop solutions to tackle FLW in the home and inform policy development.

Although few diary studies were found for non-household parts of the supply chain, they have the potential to be used in any setting and could be especially useful where more technical solutions are unaffordable. One key strength is that they can quantify FLW going to destinations that are otherwise difficult to measure: FLW from households going down the sewer, fed to animals or composted in the backyard.

Despite all these advantages, diaries generally underestimate the amount of FLW generated. Current research is exploring this underreporting and seeking to understand what factors affect the degree of underestimation.

Table 16. Summary of Diaries as Applied to Different Sectors

Sector	Coverage of Method
Primary production	Rarely used
Processing and manufacturing	
Wholesale and distribution	
Retail	
Food service/institutions/out-of-home consumption	Used as an alternative to smart bins
Household	Multiple examples using a range of methods

Conclusion: Diaries

Diaries can provide highly granular information about the amounts and types of food being wasted or lost. A strength is that they can provide information about why an item was thrown away, and there are numerous examples of information from diaries underpinning intervention and policy development. They can also be used on material flows that are otherwise difficult to measure (e.g., FLW to sewer). However, diary-based estimates can be inaccurate, generally underestimating the amount of FLW.

3.5 Questionnaire Surveys

Questionnaires, commonly referred to as surveys, involve the questionnaire respondent answering structured questions that have been written down in advance. They can be administered using a range of modes (e.g., face-to-face, over the telephone, on paper and, increasingly, through a digital interface).

They have been used in a few different ways to gather information relating to FLW and food surplus:

- Questionnaires that ask respondents to provide existing quantification of FLW (e.g., asking businesses to supply estimates of food waste from their facilities, measured in a standardized way).
- Questionnaires that ask for other information allowing the researcher to estimate FLW (e.g., enquiring about FLW containers, such as their size, fullness and frequency of collection, or the inputs and outputs of a facility for a mass balance approach).
- Questionnaires that ask the participant to recall the amounts or types of food waste, loss or surplus.

The last of these three types of questionnaires is fundamentally different from the first two. For this reason, this section is split into two parts, with the first considering questionnaires that collate existing data and the second looking at questionnaires as a quantification tool. More details of questionnaire surveys can be found in the annex on quantification methods of the *FLW Standard* (Section 7).

3.5.1 Examples of Questionnaire Surveys

Questionnaires to Collate Existing Data

Using questionnaires, or more generally, standardized forms to obtain data from a person or organization is a relatively cost effective and straightforward way of obtaining existing information. It has commonly been used to collate information from businesses across the supply chain. It has been less widely used for households.

Alongside supporting change, collecting data via questionnaires or forms is an important part of many voluntary agreements, in which the coordinating organization may request information on the quantities of a range of types of FLW. This information is often used to track progress against a target. In addition, it can be used to benchmark companies supplying data, identify hot spots, and develop a strategy for achieving the targets.

Examples span primary production (COMCEC 2016, Delgado et al. 2017, WRAP 2017a), manufacturing and retail and whole supply chain approaches (Food Waste Reduction Alliance 2014, VCMI 2018, Statistics Canada 2018).

There are several points to consider when obtaining information using this method:

- **How have FLW and food surplus been quantified?** The quality of the data being supplied will be partly determined by how it was collected. If high-quality data are required, understanding how the data were obtained is an important verification step.
- **Ensuring common understanding** of definitions and information sought. This often requires additional activities, such as focus groups to refine the survey, workshops explaining the data required, one-to-one discussions and, potentially, site visits.
- **Specific yet flexible**: it is usually important for the information obtained from these surveys to be "compatible"— that is, allowing data to be added up or compared. However, there may be instances where it is acceptable for there to be differences between what companies report (e.g., if some companies can report a higher level of detail, it would be useful to obtain this, even if all companies cannot match that detail). Building in flexibility to the questionnaire is useful.
- **Burden on respondents:** as responding to a questionnaire takes time, minimizing the burden on companies (ideally, giving something back for taking part, such as a bespoke analysis) can increase the response rate.

- **Commercial sensitivities:** many companies will require that the information supplied only be used and reported in certain ways. For instance, some voluntary agreements only report information from a sector in total; no information from individual companies is disclosed. It is important to build up trust between the reporting companies and the organization receiving the information, and this may take many years.

Table 17. Using Questionnaires Focused on Collating Existing Data

Strengths	Limitations / Points to Consider
• **Is a cost-effective method of collating information** • **Can standardize the information requested from each interviewee**	• Relies on third parties • Can be challenging to extract the exact type of information needed; can be difficult to ensure that collated information has the same definition and scope of FLW • Questionnaire may have to be flexible to accommodate different levels of information (e.g., granularity of data) • Can be limited by commercial sensitivities and confidentiality • Is unlikely to include information on root causes (i.e., the reasons why food is thrown away)

Questionnaires as a Quantification Tool

Questionnaires as a quantification tool have largely been deployed in the home and in out-of-home consumption settings (e.g., restaurants). A range of question types has been used. These include:

- **Absolute amounts:** asks participants to report on the amount of FLW in their home, without the use of diaries or other instruments. Can be asked to report in weight, volume (e.g., number of cups) or number of items (for certain categories).
- **Proportional waste measurement:** participants are asked to report the percentage or proportion of food brought into the household that is discarded. Can be applied to total food, categories of foods (e.g., fruit) or individual foods (e.g., bananas).
- **Frequency measures:** asking participants to report on how frequently a given food category is discarded.
- **Qualitative categories:** using qualitative descriptions of amounts discarded (e.g., none, hardly any, a small amount, some, a large amount).
- **Pictorial representation of amounts/use of images:** this variant uses visual prompts to aid the response given.

A table listing relevant studies can be found in Annex 1 of van Herpen et al. (2016). Only one questionnaire-based study from North America is listed: Parizeau et al. (2015). The paper by van Herpen et al. also notes the most detailed study comparing results from questionnaires with other measurement methods. This compared two different questionnaire variants alongside diaries, photo diaries and the use of caddies to quantify food discarded in the home.

The results indicated that both types of questionnaire substantially underestimated the amount of food discarded in the home. However, one of the questionnaire methodologies (in which, a week before the questionnaire was administered, households were alerted to the fact they would be asked about their FLW) had a high degree of correlation with other measurement methods. This suggests that it may be suitable for classifying households according to the amount of food they waste, even if it still provides an underestimate of the absolute amount of FLW. It is not known whether questionnaires underestimate FLW by a similar amount over time or across cultures. Therefore, it is not known whether a questionnaire is a reliable quantification measure for tracking purposes or monitoring intervention studies.

Table 18. Questionnaires as a FLW Quantification Tool

Strengths	Limitations / Points to Consider
• **Relatively cost-effective to administer** • **Can provide data by food group or preparation stage** • **Can provide information by demographic group or other characteristics** • **Can provide data on root causes of waste and help identify hotspots**	• Respondents tend to underestimate the amount of food waste due to aspirational biases • It is not yet known how this underestimation varies over time, between groups and during intervention studies

3.5.2 Summary: Questionnaire Surveys

Questionnaire surveys are an inexpensive way to collate existing data. They benefit from good relationships between the organizations collating and providing the information to increase participation in the survey and overcome any sensitivities around providing data.

The accuracy of estimates derived from this information will depend on the quality of the data collected. When obtaining an estimate of FLW from information provided by questionnaire, it is important to ensure that the user of the data is aware of how the FLW was originally quantified and the definitions/boundaries used.

A range of examples can be found across the supply chain, in a range of settings including academic studies, reporting with voluntary agreements, and whole supply chain initiatives.

Table 19. Summary of Questionnaire Surveys for Collating Existing Data as Applied to Different Sectors

Sector	Coverage of Method
Primary production	Examples of questionnaires for all sectors
Processing and manufacturing	
Wholesale and distribution	
Retail	
Food service / institutions / out-of-home consumption	
Household	None known

Questionnaires as a quantification tool have been used frequently for household FLW and occasionally for out-of-home consumption FLW (e.g., front-of-house restaurant FLW). However, it comes with one significant pitfall—a high degree of bias because of systematic underreporting. Questionnaires can be used to give approximate information, suitable in some circumstances for understanding the approximate scale of the problem and identifying problem foods. However, the method requires significant development before it can be used to track targets or be used for other purposes that require accurate data.

Table 20. Summary of Questionnaire Surveys as a Quantification Tool for Different Sectors

Sector	Coverage of Method
Primary production	None known
Processing and manufacturing	
Wholesale and distribution	
Retail	
Food service/institutions/out-of-home consumption	
Household	Numerous variants used

Conclusion: Questionnaire Surveys

Questionnaire surveys have been used in two distinct ways.

In the supply chain, they are often used to collate existing data on food loss, waste and surplus. This is often to obtain a national or subnational (e.g., provincial, state) estimate, often by a government or trade association. The estimates generated from this information can only be as strong as the data itself, so the questionnaire process should be designed so information on quantification methods and scope/boundaries is also captured. In addition, commercial sensitivity of the data can hinder this approach.

In the home, there are numerous examples of questionnaires being used to estimate the amount and type of foods being wasted. These examples suffer greatly from underreporting and should be used with caution. However, the results from some variants correlate well with other methods, so they may have a role in identifying households with high or low levels of wasted food.

3.6 Inference by Calculation

This section describes quantification methods where the amount of FLW or food surplus has not been measured directly. Instead, the methods described infer the amount of FLW by some form of calculation, including mass balance, modeling and use of proxy data. These have been combined into a single section as there is much overlap between them. In addition, many examples use two or more of these methods in a single quantification study. The methods discussed below have been applied to all the supply chain stages, including households.

The mass balance approach infers food loss, waste or surplus by comparing inputs (e.g., products entering a grocery store) and outputs (e.g., products sold to customers) alongside changes in levels of stock. In some sectors, changes to the weight of food during processing (e.g., evaporation of water during cooking) have to be considered too. This method can be applied to individual or multiple stages of the food supply chain. More details of this method can be found in the annex on quantification methods of the *FLW Standard* (Section 8).

Models infer the amount of food loss, waste or surplus using calculations. A model is a simplification of the real world. A quantitative model uses a mathematical approach to estimate food within material flows based on the interaction of multiple factors that influence the generation of FLW (e.g., grain storage practices and weather conditions). More details of this method can be found in the annex on quantification methods of the *FLW Standard* (Section 9).

Proxy data are food-related data that is from a geography, company, facility or time other than that for which the quantification is required. Proxy data is often used if other quantification methods are not feasible (e.g., because of a lack of access to the food waste to be quantified or a limited budget). More details of this method can be found in the annex of the *FLW Standard* on quantification methods (Section 10).

The main advantage of these methods is generally cost. They usually rely on existing data that can be reanalyzed or repurposed to estimate FLW or food surplus much more cost effectively than undertaking a new program of fieldwork. However, there may still be a large cost associated with the organization that does collect the original data. The US federal government, for example, provides considerable resources to collect and maintain the underlying data for the loss-adjusted food availability (LAFA) data set each year.

When existing data are used, the methods do not necessitate physical access to the FLW or food surplus being quantified. For these reasons, they are often used by governments, intergovernmental organizations, academics and NGOs (i.e., organizations that do not have direct access to the FLW or food surplus). Many examples of inference by calculation suffer from low accuracy, which is often compounded by difficulties in quantifying the degree of accuracy.

Specific examples are given below. One important point is that a program of change cannot be monitored using proxy data, as this proxy data will refer to other geography, facilities or time.

3.6.1 Examples of Inference by Calculation

Apply Loss and Waste Factors to Food Flows

The most commonly cited estimate of global food waste comes from a 2011 report published by the Food and Agriculture Organization of the United Nations (FAO): *Global Food Losses and Food Waste: Extent, Causes and Prevention* (FAO 2011; detailed methodology published later [FAO 2013]). This study uses a modeling approach based on secondary (existing) data to estimate the food losses and waste by:

- Commodity group (e.g., cereals, roots and tubers, oilseeds, pulses)
- Region of the world (e.g., North America and Oceania, Latin America, sub-Saharan Africa)
- Supply chain stage (e.g., agricultural production, post-harvest handling and storage, consumption)

The fundamentals of this method were to take the amount of each commodity group produced and apply loss and waste factors describing the percentage of that food production that was lost or wasted at each supply chain stage. Food production data is taken from the FAO Statistical Yearbook 2009 and FAO Food Balance Sheets (FAO 2009, 2018).

The loss and waste factors varied by commodity group and by region of the world. The values used were informed by an extensive literature review and discussions with experts. Many of the values came from published sources, but missing values were based on assumptions and estimations.

The definitions of FLW used in this study included a distinction between loss and waste consistent with the FAO definition (see Section 2.1). The methodology aims to quantify only the wasted food; inedible parts associated with food are excluded from the estimate. Furthermore, it categorizes food fed to animals as either a food loss or waste (depending on the supply chain stage), as the definition used is food not consumed by humans.

The information in *Global Food Losses and Food Waste: Extent, Causes and Prevention* has been used by many others to estimate food loss and waste for a specific country or region. Most relevant to this report is the use of this information in *Characterization and Management of Food Waste in North America: A Foundational Report* (CEC 2017b). This presents estimates for Canada, Mexico and the United States based on the loss factors found in the 2011 FAO report (North America and Oceania factors were used for Canada and the United States; Latin America factors were used for Mexico). These were applied to food balance sheet data for 2007.

An approach similar to that of the FAO 2011 report has been used in Israel (Leket 2018). This study used loss and waste factors calculated from a national agricultural waste survey and from the wider literature. These factors are applied to information on production, imports and exports, and consumption patterns. (Full methodological details were not presented).

A similar approach was also adopted in Switzerland (Beretta et al. 2013). This research obtained loss and waste factors from the literature, records of businesses in the supply chain and proxy data (e.g., data from households in the United Kingdom were used as a proxy for Swiss households). This paper focused on the (edible) food and did not attempt to quantify the inedible fraction associated with food. The research used energy as the quantification metric.

Another method in this vein was developed for the Excess Food Opportunities Map in the United States. This involved a data-driven model to estimate the generation of excess food (i.e., FLW and food surplus food) by industrial, commercial and institutional sources and to identify potential recipients of this surplus (EPA 2018). Establishments with the potential to generate surplus food were grouped into food manufacturers and processors, food wholesalers and distributors, educational institutions, the hospitality industry, correctional facilities, healthcare facilities and the food services sector. Estimates of excess food were generated by combining statistics on the number and nature of businesses in these sectors with equations that correlate business statistics with excess food generation.

The African post-harvest loss information system (APHLIS) focuses on the food losses that occur in sub-Saharan Africa in the post-harvest stages of the supply chain, that is, on-farm processing and distribution (Hodges et al. 2014). APHLIS itself is a database system that allows local experts for each country to supply (and check for quality) post-harvest loss data in a standardized way. This information can then be used to support formulation of agricultural policy, identify opportunities to reduce post-harvest losses, tackle food insecurity, and monitor activities designed to reduce losses.

APHLIS differs from the other approaches described here in two ways. One, the estimates of post-harvest loss are calculated from two data sets: the post-harvest loss profiles and the seasonal data. A post-harvest loss profile is a set of figures; there is one figure for each link in the post-harvest chain for each commodity. These are obtained from a detailed search of the literature followed by a screening process, and are largely unvarying over time. The seasonal data are contributed by local experts and represent factors that can affect post-harvest loss that can vary between seasons and from year to year.

Secondly, APHLIS is an ongoing project, rather than a single piece of research. Information from programs that measure the amount of post-harvest loss is used to update the post-harvest loss profiles so that changes over time are reflected in the resultant estimates.

The description of the resultant estimates of post-harvest loss derived from APHLIS is careful to stress that these are "… not intended to be 'statistics' although they are computed using the best available evidence; they give an understanding of the scale of post-harvest losses using a 'transparent' method of calculation" (Hodges 2014).

The APHLIS website includes a number of useful resources: country narratives, in which country experts can post a commentary on post-harvest losses; interactive maps to explore the data; and a calculator to enable people to tailor calculations for post-harvest losses to particular geographic boundaries or to model hypothetical scenarios.

Table 21. Apply Loss and Waste Factors to Food Flows

Strengths	Limitations/points to consider
• **Is relatively cost effective to produce estimates** • **Uses best available secondary data** • **Provides information by region, commodity group and supply chain stage**	• Loss factors in model have varying degrees of accuracy and consistency (e.g., they may use different definitions of FLW) • In most situations, a relatively high proportion of data is missing: using proxy data introduces (potentially large) inaccuracies, the magnitude of which is difficult to estimate

Mass Balances

There are several examples of mass balances used to quantify FLW. Those reviewed below generally consider mass balance at a national level; there are examples from Mexico and the United States. No examples from Canada were found. Mass balance could also be applied at a facility or company level using records of input (e.g., ingredients) and outputs (e.g., products), but few examples exist in the public domain.

In Mexico, a yet unpublished report written in 2017 for the World Bank presented to the CEC models of FLW between the primary production stage (farm gate) and the point of food purchase by consumers (Aguilar Gutiérrez 2017). It covered the 79 most-consumed products in the country, which amount to approximately 80% of total food consumption. Because of the restrictions imposed by the modeling method, results were calculated in aggregate, rather than presenting data for each sector individually.

On the input side, this report takes commodity production data from the Mexican Agri-food and Fisheries Information Service (*Servicio de Información Agroalimentaria y Pesquera*). The production data excludes post-harvest losses. Imports were added to these production data and exports were subtracted from them, leaving a figure for food availability from production in Mexico before losses occur. The author took production information only on products that could be traced all the way to an equivalent in the consumption data he used. On the output side, the report takes information from a regular Mexican National Institute of Statistics and Geography (*Instituto Nacional de Estadística y*

Geografia [INEGI]) survey. This is a biennial national survey of household income and expenditure.[14] The survey micro-data allowed the author to find the reported weight of products bought by a sample of Mexican households and cross-reference the weights with the production data from the Agri-Food and Fisheries Information Service (*Servicio de Información Agroalimentaria y Pesquera*) (Mexico). This includes purchases made outside of the household (e.g., at a restaurant).

The mass balance data in the World Bank report were reached, on a product-by-product basis, by subtracting the food purchased by citizens and consumers in Mexico from the food available in the supply chain after primary production, leaving an estimate of loss and waste for each product. The supply chain stages included were storage, processing and distribution, retail and wholesale, and hospitality and food service (before consumer plate waste).

The World Bank report was designed to give an indication of the scale of FLW in Mexico, and therefore does not attempt to drill down into specific destinations for food leaving the human supply chain. For example, Mexico has the world's second largest food bank network and food redistribution done by the Mexican Food Bank Association is a very significant part of the food recovery flow in the country, and this nuance is not perfectly reflected by the report's quantification method. The mass balance method used counts any food that leaves the supply chain before purchase as loss or waste when, by many definitions, food redistributed to feed people, or food used to make animal feed is not considered a loss or a waste.

The USDA has used mass balance for a subset of its food-loss estimates that form part of the LAFA data series (Buzby, Wells and Hyman 2014). The primary aim of the LAFA data series is to estimate food intake for the US population per capita. However, in calculating this data series, estimates of food loss are also generated, which are reported separately. Most of the loss estimates in the LAFA are based on the method that applies loss and waste factors to food flows (see above).

The foundation of the LAFA data series is the food-availability data series, which are food balance sheets. These are referred to as "supply and use" or "supply and disappearance" spreadsheets. These are part of the USDA's Food Availability (Per Capita) Data System, which also provides separate documentation for each of its data series.[15]

However, for the food that is lost in the home, a mass balance approach is used. This involves subtracting the amount of food and drink consumed, as measured by a recall survey (National Health and Nutrition Examination Survey) from the amount of food and drink purchased. The latter data are provided by a sales-data company, Nielsen Homescan (Muth et al. 2011).

The LAFA data sets also use a mass balance to obtain loss factors for fresh fruits and vegetables at the retail level. The loss factors are estimated by subtracting the amount of these commodities sold at retail from the inbound shipments to the retailers (Buzby et al. 2009). The USDA's ERS updated this retail loss study using the same approach (Buzby et al. 2015, Buzby et al. 2016). These estimates were reviewed by an expert panel in 2017–2018 that recommended the adoption of these estimates for fresh fruits and vegetables in the LAFA data series. The LAFA data were updated with these estimates and posted on the ERS website in fall 2018.

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[14] See www.beta.inegi.org.mx/proyectos/enchogares/regulares/enigh/nc/2016/default.html.

[15] See www.ers.usda.gov/data-products/food-availability-per-capita-data-system.aspx.

In 2016, an article was published looking at the lessons learned from estimating food loss at the retail and consumption stages of the supply chain (Buzby and Bently, 2016). Several challenges were described, including:

- It was difficult to compare food-purchase data and intake data for multi-ingredient foods that are prepared in the home (e.g., wheat flour entering the home that is used to make a range of items such as bread, cookies, rolls).
- Calculation of accurate loss factors was not possible for some commodities (e.g., rye flour, cornstarch) because of sample size limitations.
- There is no distinction in the LAFA data between loss associated with at-home consumption and away-from-home consumption.
- The current method does not allow consumer-level food loss to be assessed by demographic or regional groups (e.g., level of education, rural or urban, age).

Another example of mass balance, again applied in the United States, is a study by Hall et al. (2009). This presents a mass balance across a range of supply chain stages, estimating food loss as the difference between food consumption and food supply. Unlike most of the calculations presented in this section, the FLW estimate presented in this paper was based on energy content, rather than on weight. Food consumption was estimated from the weight distribution of the US population, using a mathematical model of metabolism, which relates the amount of food eaten to body weight. Food supply is estimated from food-availability data that form part of the balance sheets published by the FAO.

Table 22. Factors to Consider When Using Mass Balance for FLW Quantification

Strengths	Limitations/Points to Consider
• **If input/output data already exist, can be relatively cost effective; otherwise can be costly** • **Can obtain estimates of FLW where no direct data exist (e.g., estimate FLW from food supply and consumption)** • **Depending on how data is collected, may help identify waste hot spots (e.g., food categories)**	• Can have large inaccuracies depending on the type of data available • Difficult to estimate uncertainties • Requires quantification of all major flows of food (e.g., food going to feed animals) • Difficult to apply if there is substantial addition or removal of water (e.g., evaporation of water during cooking) • May be difficult to determine root causes

Synthesis Methods

One important method for calculating FLW contained within mixed waste streams is the synthesis method. This involves combining data on the total amount of waste contained within a waste stream with estimates of the proportion of that waste that is food. These estimates of the proportion often come from waste composition analysis (Section 3.2).

A recent academic paper involved such a study, collating and analyzing data from Ontario, Canada (van der Werf et al. 2018). Household waste data were collected from 28 waste composition analysis studies, spanning nine municipalities in Ontario and relating to single-family (i.e., detached or semidetached) homes. These studies included a single “food waste” category and used a common waste composition study methodology, which facilitated combining the information into a single synthesis-type analysis. This allowed an estimate of FLW in the garbage (residual) waste stream to be quantified and confidence intervals to be calculated.

There are several examples of synthesis studies outside North America. The UK government's Department of Environment, Food and Rural Affairs (Defra) has undertaken a couple of synthesis studies for municipal waste streams (with separate data for the subset of municipal waste coming from households). These focus on all materials found, including estimates for the food within these waste streams (Defra 2009, Defra 2013).

This type of approach was adopted in three food-focused synthesis studies applied to household FLW by WRAP (WRAP 2011, WRAP 2013b, WRAP 2014a). These studies refined the method developed by Defra. Investigation of factors that correlated with the amount of FLW found in the relevant waste streams was undertaken in these studies. This led to the waste composition analyses used in the study that was stratified according to the type of collection targeting food waste, to improve the calculations and increase the accuracy of the results. Consistent application of this method has been used to track household FLW in the United Kingdom over a decade. This allowed identification of a substantial reduction between 2007 and 2010, followed by a period where household FLW levels per person remained broadly similar. These results allowed national policy relating to FLW prevention to be developed and refined.

At the time of writing, the Canadian government is undertaking a synthesis study similar to that described above. This method has also been applied in Mexico for a World Bank project (currently unpublished) to establish a provisional estimate of FLW in municipal waste streams. The United States uses an alternative (but similar) method using waste composition analysis to determine generation rates for residential properties (EPA 2016c).

Table 23. Synthesis Methods

Synthesis Methods: Strengths	Limitations / Points to Consider
• **Relatively cost-effective** • **Can be highly accurate (depending on the quality of data sources and the number of waste composition studies)** • **Has been used successfully for tracking household and municipal FLW nationally**	• Dependent on the quality of underlying data • Usually not possible to obtain information on the food types contained within FLW or the reasons for discard

3.6.2 Summary: Inference by Calculation

A model is only as good as the data it is based on. This is as important for FLW-related studies as in any other area. When inferring the amount of FLW or food surplus using calculations, it is important to assess the quality and appropriateness of the underlying data. A short checklist is provided below to help in this exercise (adapted from FUSIONS 2016):

- **Timeframe and geography:** do the data come from the time and place in question?
- **Quantification method:** how were the data measured or inferred, and is this accurate enough for the purposes for which the data are being used?
- **Definitions:** is the definition of what is measured (e.g., food waste) close enough to that of the current study?
- **Sampling:** where sampling occurred, was its design and execution good enough to provide an estimate representative of the whole?

In many cases, there are data gaps in models. Estimates and assumptions used to fill these gaps should be tested. At the very least, the sensitivity of the final estimates to the values used should be tested and documented; and at a minimum, this should involve varying the assumed values within realistic bounds and observing the impact on the results. For complex calculations on which important decisions will be based, methods such as Monte Carlo simulation should be considered.

In addition to data quality, the modeling method itself can influence the accuracy of the estimate. In the example of mass balance, the fact that the method relies on subtraction means that the relative accuracy (expressed as a percentage of the value) of the resultant estimate is much lower than the accuracy of the data used to create the estimate.

Estimates of FLW and food surplus inferred by calculation are generally good enough to provide a ballpark estimate of the total quantity and, in some cases, more granular information below this total. This relatively low level of accuracy may be sufficient for many decisions to be made. For instance, in a country, it may be sufficient to determine which are the priority sectors (i.e., those generating the most food loss and waste) or the priority food groups.

However, most existing calculation-based methods, with the exception of the synthesis method, are not currently accurate enough to track progress against a target or monitor a program of interventions. Specifically, the data underlying the model are not usually updated frequently enough to support tracking. This need not be the case in all circumstances (e.g., if the modeling method were supported by a program of measurement designed to provide up-to-date data). Such a measurement program usually increases the cost of quantification substantially, which negates one of the key advantages of these methods: their relatively low cost.

Table 24. Summary of Inference by Calculation as a Quantification Tool for Different Sectors

Sector	Coverage of Method
Primary production	Factors applied to food flow
Processing and manufacturing	Factors applied to food flow
Wholesale and distribution	Factors applied to food flow
Retail	Factors applied to food flow
Food service/institutions/out-of-home consumption	Factors applied to food flow
Household	Factors applied to food flow Mass balance applied Synthesis approach
Multiple supply chain stages	Mass balance applied to primary production through to retail Mass balance applied Synthesis approach applied to municipal waste streams

Conclusion: Inference by Calculation

Inference by calculation is often used as it is a cost-effective method that makes use of existing data. The accuracy of the ensuing estimates depends heavily on the accuracy of the underlying data. For calculations that apply wastage factors to food flows, there is a need for more accurate and recent data to support these studies. With calculations using a mass balance approach, the method magnifies inaccuracies—small inaccuracies in the input data can lead to large inaccuracies in the FLW estimates. It is important for users of these methods to understand the approximate magnitude of uncertainties in the estimate to assess whether an estimate is good enough for a given purpose.

3.7 Quantification Methods Specific to Sewer Waste

This section provides information on the methods currently used for FLW that goes into a sewer. Lost or wasted food that is discarded through the sewer network is often overlooked during quantification studies, but for some businesses, the sewer is the single largest destination for food waste (Taylor 2018). Sewer waste can be particularly important in certain types of manufacturing and processing sites (especially dairy, juice manufacturers and other facilities that use the sewer to dispose of FLW). It can also be important in commercial kitchens where there is a sink disposal unit that macerates waste before sending it into the sewer system. It can also be important for populations of households that have a high proportion of these disposal units; for example, an EPA study estimated that around 25% of consumer-level food loss is disposed of via the sewer system (EPA 2013). Therefore, omitting FLW that goes into the sewer can substantially influence decisions made; it can lead to underestimation of the total amount of FLW and can cause the focus to fall on FLW found in other waste streams and material flows (e.g., landfill).

In business settings, where FLW is discarded to the sewer network or to an on-site treatment facility, a flow meter can be used to measure the total volume of liquid. This volume can be converted to weight using the appropriate density value for the liquid. However, in many cases the FLW passes down the pipes mixed with other liquids, for example, with wastewater. There are a few methods of estimating the quantity of FLW. These involve measuring one or more metrics linked to the composition of the liquid in the pipe and using a conversion factor to estimate the FLW.

Chemical oxygen demand (COD) is a measure of the amount of oxygen needed to oxidize the organic compounds in effluent using a chemical oxidant (expressed in milligrams per liter). It is frequently measured as, in many countries, facilities are charged according to the COD associated with what they discharge to the sewer network. For example, dairies often take the total COD in their liquid waste and estimate the amount of raw milk that this is equivalent to, which gives an estimate of how much FLW is going into the sewer from a range of dairy products.

Other potential metrics for estimating FLW in a sewer network include biological oxygen demand, total suspended solids, total dissolved solids and total organic content.

If a facility has an on-site treatment plant for sludge and sewer waste, the monitoring point to estimate FLW must be prior to this treatment plant, as the treatment process will alter food being wasted (e.g., by removing or destroying it), influencing the values measured.

Further information on measuring FLW in sewer waste can be found in Chapter 3 and Appendix A of the quantification methods annex to the *FLW Standard*.

In household settings, diaries have been used to estimate the amounts and types of food and drink waste going to the sewer (see Section 3.4 for more details).

Table 25. Quantifying FLW Going to the Sewer

Strengths	Limitations/Points to Consider
• **Often already measured for billing purposes** • **Where single product is being discarded, estimates can be relatively accurate** • **Conversion factors for many products already exist**	• Requires infrastructure for measurement and sampling (e.g., flow meters, COD testing) • Works best where a single product (or a small range of products) is in flow; can be difficult where multiple products are mixed

Table 26. Summary of Sewer Waste Methods as Applied to Different Sectors

Sector	Coverage of Method
Primary production	No studies known
Processing and manufacturing	A range of methods used, little published information
Wholesale and distribution	No studies known
Retail	No studies known
Food service/institutions/out-of-home consumption	No studies known
Household	Diaries used (see Section 3.4)

Conclusion: Methods Specific to Sewer Waste

Despite a lack of published information, there are a few methods for estimating the amount of FLW going into the sewer. These are based on a range of metrics (e.g., COD, biological oxygen demand, suspended solids) and have generally been applied in the processing and manufacturing sectors, where such measurements are already routine because of various regulations.

3.8 Methods Integrated into a "Change Process"

There are many examples of quantification methods integrated into a "change process" (i.e., a program aimed at preventing or diverting FLW where quantification is one of several steps designed to bring about change). This section outlines some examples across the supply chain; some are aimed at businesses and some are aimed at governments and NGOs.

Primary Production

A few methodologies have recently been developed for creating change in primary production with regard to FLW. The commodity systems assessment methodology is designed to identify weaknesses in agricultural supply chains that have the potential to cause FLW. It is also designed to identify solutions for improving the efficiency of these supply chains (La Gra et al. 2016).

Manufacturing and Processing

The Provision Coalition's Food Loss and Waste toolkit (based on Enviro-Stewards' source-reduction-based approach) is a good example of an approach in which quantification is one important step in a process to help companies to prevent their food loss and waste. The toolkit involves estimating the amount of FLW being generated in a process or facility and using a range of data to estimate its impact: the cost to the business, GHG emissions, electricity, gas and water used in the facility that are wasted and the number of meals this is equivalent to (estimated using energy content of the food). The toolkit splits the costs and environmental impacts into three:

- Embedded in incoming ingredients,
- Added within the facility itself (e.g., water, electricity and natural gas used in the manufacturing process), and
- Disposal or treatment.

This ensures that the focus is not narrowly constrained to the cost and environmental impact of disposal and treatment, where the cost and impact are often much smaller than the other two categories.

The toolkit also guides the user to understand the reasons why the FLW is generated and supports development of solutions and their implementation. The toolkit could also be deployed in other sectors, such as retail.

Similar in scope to the Provision Coalition's toolkit is the US EPA's guidance (EPA 2014). This involves food waste quantification as part of a wider assessment to tackle food waste. Quantification can involve direct measurement (e.g., counting, weighing), supplemented by site audits to help understand the root causes of waste generation.

Households

Various tools are available for households to quantify their own food waste to allow them to prevent food waste in their own home. The US EPA has produced a three-page document taking households through this process (EPA 2016b). The tool encourages households to measure their food waste by collecting it in small garbage bags and weighing it. It asks households to do two weeks of baseline measurement and then implement one or more strategies to reduce waste while continuing to measure food waste for four more weeks.

Diary-based methods have also been developed for households (e.g., in Australia [Victoria State Government no date]). Not only do they allow households to quantify their food waste, but they can also record the reasons why they throw food away, a first step in helping households to create solutions. An example from Banyule City, Australia, uses diaries as a way of engaging householders in a process of change (Verghese et al., 2014).

Whole Supply Chain

There are a few examples of whole supply chain approaches to tackling food loss and waste.

Value Chain Management International Inc. (VCMI) regularly conducts work to prevent food from being wasted, taking a whole supply chain perspective. The firm uses a range of diagnostic tools to uncover where waste occurs, quantify it, and participate in implementing the solution. Examples of this approach can be found in case studies (VCMI 2017).

The United Nations Environment Programme (UNEP) produced guidance for governments, local authorities, businesses and other organizations "to catalyse action around the world by sharing proven methodologies for food waste prevention" (UNEP 2014). The guidance contained four modules; measurement was an important part of all of them, including quantification to help understand the nature of the problem, and quantification as an important part of monitoring and evaluation.

In the United Kingdom, the Institute of Grocery Distribution and WRAP developed a resources guide to support businesses in taking action on food waste prevention and diversion. It covers food production, manufacture, distribution, retail, and hospitality and food service. The document outlines a set of principles for measurement and taking action and has signposts for the reader to appropriate guidance elsewhere. Of particular interest is Your Business Is Food: a suite of resources to guide businesses through the process of acting, including quantifying their waste and building a business case for reducing it.

In addition, there is one type of research that is useful across the supply chain to develop the deep understanding required to generate solutions and create change: ethnographic-based methods. These involve observing and talking to people about the activities related to FLW or surplus generation, redistribution, diversion or disposal. This could involve semi-structured interviews, accompanied shopping trips, and asking people to talk through the contents of their fridge. These have mainly been

Conclusion: Methods Integrated into "Change Process"

There are numerous examples of quantification embedded within a change process. The key advantage of these is that people involved understand why they are quantifying, and it narrows the gap between quantification and acting to tackle the issues. The linking of quantification to change is likely to influence some measurements (e.g., people may change what they are doing, even during a baseline measurement), so care should be taken about how estimates obtained in this way are used.

applied in households—for example, in Oregon in the United States (Moreno et al. 2017) and in the United Kingdom by Evans (2012) and Watson and Meah (2013). It has also been applied to food service in hospitals in New Zealand (Goonan et al. 2014).

3.9 Reconciling Data

Sections 3.1 to 3.5 of this chapter discussed a range of methods for measuring FLW. As mentioned in Section 3.6, if data already exist that can be used for quantification purposes, it is often more cost effective to use this information rather than to collect new data. However, the existing data may not be comprehensive. In Section 3.2, advice is given on how to reconcile WCA data that have not been collected as part of a standardized program. This current section gives general advice on reconciling data. This is useful when comparing or combining estimates of FLW (e.g., using data from different municipalities to obtain a national estimate).

When reconciling data, it is easiest to use consistent data. Below is a checklist, specific to FLW, that can help determine the level of consistency between estimates:

- **Timeframe:** What timeframe did the estimate aim to represent and when did sampling take place?
- **Geography:** What geographical area was being represented and what were the sampling locations?
- **Destinations:** What destinations or material flows were quantified (e.g., did it only cover material bound for landfill, or were other destinations included)?
- **Boundaries**: What types of organization, facilities and premises are included? For example, was a waste composition analysis for just households or did it include non-household waste too? If for retail, what types of store were included and were distribution centers included too?
- **Materials included**: Did the estimate cover wasted food and inedible parts? Which food categories were included? For food in its packaging, was the weight of packaging included in the estimate?
- **Measurement methods:** What method was used and how was it deployed?
- **Sampling (**if applicable): How was the sample determined?
- **Units:** Is the estimate per capita, per household, per store?
- **Weighting/stratification of the sample** (if applicable): What are the details of any weighting and stratification used to calculate the total from the sample data?
- **Seasonality:** Was seasonality considered in the sampling or any subsequent calculations?

If there are differences in any of the above, it may still be possible to reconcile the data, but extra care is needed. For instance, it is possible to reconcile data through comparing a subset of the data. If there are differences in the categories of food included, it may be possible to make a comparison on a subset of the categories (i.e., those included in both).

If different quantification methods have been used, this is more problematic. As an example, reconciling data from households measured by questionnaire surveys, diaries and waste composition analyses is difficult because differences in the design of the surveys and diaries can influence the level of bias in the results. Some studies exist that have compared specific surveys and diaries (e.g., van Herpen 2016), but other surveys and diaries may underestimate FLW to a different extent.

Depending on the data held, further analysis can help reconcile the data. Regression analysis was used on waste composition data to understand how differences in methodology were affecting the results (WRAP 2018b). For instance, waste composition analysis that included a “packaged food” category (rather than separating all packaged food into the food and the packaging) had higher estimates of food waste compared with those without. This allows correction factors to be developed and applied to studies to allow them to be compared or added together.

Whether reconciling data is advisable also depends on how the information is going to be used. The more accurate that a comparison needs to be, the more challenging the reconciliation process.

In summary, it is best to collect and collate data that is entirely consistent. In practice, this is rarely the case and it is sometimes possible to reconcile inconsistent data. However, this process requires attention to detail. A list of factors to be considered is provided to avoid the numerous pitfalls of reconciling data.

3.10 Summary of Quantification Methods

This chapter has discussed a wide range of quantification methods and how they have been deployed. Many of these are either well established or have been used often enough for the strengths and weaknesses to be reasonably well understood in a range of situations. Some of the methods require further work before how they operate, their accuracy and the biases inherent in them can be assessed.

Despite knowledge of the methods' strengths and weaknesses, the choice of method is not always easy. In many situations, the approach that is most accurate or provides enough granular data to understand the issue may be prohibitively expensive. This means that suboptimal methods also need to be considered, requiring comparison of different compromises and trade-offs. This process is more straightforward if the organization in question is clear about what it would like to achieve from quantifying FLW and how this information will be used. In many situations, it is possible to achieve FLW-related aims with rough estimates or without quantification at all (e.g., using qualitative information).

This chapter has largely focused on methods that have been in existence for many years, if not many decades. However, there are a few new innovations that could alleviate common dilemmas relating to cost and accuracy. For instance, in Section 3.4, the use of digital photography to quantify FLW that is left over after meals was discussed; this is a very recent advancement. There have also been discussions about the use of blockchain and artificial intelligence to quantify and manage food (and FLW) in the supply chain. At the time of writing, there is little information in the public domain on how these technologies are being used, but this is likely to be an area of change in the next few years.

This chapter has highlighted different types of approaches being used by governments and businesses. This reflects the fact that businesses usually focus on their own part of the supply chain, have access to their own FLW and often need to gather information to inform the business case, followed by ongoing monitoring to ensure they achieve the intended savings. In contrast, governments and NGOs often require information on a range of stages of the supply chain. Except for municipal solid waste, they often do not have direct access to the material flows and waste streams they are seeking to quantify. They are often the organizations that quantify FLW in the home. Finally, they are looking to collect information to develop policies and track changes for national and international targets. These differences between the two groups will be reflected in the practical guide, suggesting methods to each group that work best for the different situations they find themselves in.

4 Estimating Environmental, Social and Financial Impacts and Benefits

This chapter presents methods used for estimating a range of impacts and benefits relating to food loss and waste (FLW) and food surplus. These are arranged into three sections: environmental (Section 4.1), financial or direct market impacts (Section 4.2), and social and other impacts (Section 4.3). In each section, current methods are discussed alongside their strengths and weaknesses in different situations.

4.1 Environmental Impacts

Food production and all its associated processes (including processing, manufacturing, packaging, distribution, refrigeration and cooking) require resources, such as arable and pasture land, fresh water, fuel and chemical inputs (e.g., fertilizer, herbicides and pesticides), and cause environmental damage, such as air and water pollution, soil erosion, emissions of greenhouse gases and biodiversity loss. This is true whether food is consumed by people or animals or is lost or wasted from the food supply chain.

Depending on how wasted food is managed, it can cause additional environmental impacts that would not have occurred had the food been consumed. These impacts are associated with transportation of waste, further land use in the form of landfill, and additional methane emissions from landfill. Although the effects are typically less than those associated with production, they can still be significant.

The main environmental impact categories identified in the literature are:

- greenhouse gas emissions (often called the carbon footprint)
- water use
- land use
- energy use
- fertilizer use
- biodiversity

The methodologies to assess these different environmental impacts are generally similar. The next section contains a discussion of the overarching themes that all impact categories have in common.

4.1.1 Overarching Themes

Environmental impact assessments can be done using different theoretical and methodological approaches; they will also differ depending on boundary and scope.

Theoretical Approaches

Two theoretical approaches are commonly used:

- Assessing the overall environmental impacts of FLW; and
- Estimating the environmental benefits of changes related to FLW (including source reduction or prevention).

The first approach (assessing the overall impacts) highlights the total environmental impacts of FLW, based on the fact that wasted food did not fulfill its primary intended purpose. Therefore, the use of resources to produce this food and the associated impact on the environment have been largely in vain. It doesn't consider any specific counterfactual scenario or the alternative uses of food. Therefore, it carries an implicit assumption that the food that is ultimately wasted would not have been produced in the first place and none of the environmental impacts associated with wasted food production and other upstream stages of the supply chain would have occurred. This kind of analysis also usually does not extend into what would happen to replace the production of food (e.g., forests planted on what had been agricultural land, or more food being available for exports), or how the reduction of waste would change prices or supply and demand dynamics.

Table 27. Overall Impacts

Strengths	Limitations/points to consider
• **Gives an approximate (first order) estimate of the impact of FLW** • **Can be compared with other high-level issues**	• Boundaries and assumptions are often not clear • Gives no information about how much of this impact could realistically be reduced

The second approach, assessing the benefits of change, flips the question: "How much was used to produce food that is wasted?" into "How much would we save if we prevented FLW?" (Similar questions are sometimes asked for moving food up the food recovery hierarchy.) Under the second approach, studies tend to assume only a set percentage of food waste can realistically be prevented and also tend to be more specific about the counterfactual scenarios. The so-called rebound effect might also be considered.[16]

Table 28. Benefits of Change

Strengths	Limitations / points to consider
• **Conceptually clearer if counterfactual is well defined** • **Often seeks to answer a research question of practical importance** • **Allows investigation of related issues and effects, such as different scenarios and rebound effect assumptions**	• Results are only valid for selected counterfactuals

[16] In the context of food waste prevention, the rebound effect describes the effect that may occur when a household avoids food waste; the household then has more money available that may be spent on other products and services, which may generate additional emissions or resource use. The environmental benefits of preventing food waste would be smaller if the rebound effect is taken into consideration. Salemdeeb et al. (2017) have estimated that the carbon benefits of FLW prevention would be 23% to 59% lower when the rebound effect is taken into consideration (but the benefits are still substantial). The rebound effect is debated because spending money on something other than food that goes unused may increase the quality of people's lives more. It is also possible to imagine (and try to design through policies) a context in which the rebound effect itself is reduced—for example, through decarbonization of other sectors such as energy and transport, or taxation of unhealthy and high-environmental-impact foods.

Methodological Approaches

In addition to the two different theoretical approaches, there are also two commonly used methodological approaches:

- Top-down approach (national sector–based)
- Bottom-up approach (using product life-cycle assessment carbon footprint as the impact factors)

Studies using the top-down approach based on national statistics on, for example, GHG emissions and water use by economic sector. They take economic sectors related to food production (e.g., agriculture) and allocate some of the sectoral impacts to FLW in proportion to the amount that is lost or wasted at that stage of the supply chain and later. The top-down approaches are relatively simple to calculate provided sectoral emission statistics are available, but do not address the differences between different types of food (for example the relatively higher impacts associated with waste of animal-based food products).

Table 29. Top-down Approach

Strengths	Limitations/points to consider
• **Simple calculation** • **Data publicly available in many countries**	• Not very accurate • Does not allow prioritization between food types

The bottom-up approach is based on the multiplication of the weight of FLW (in environmental accounting, known as activity data) and specific GHG, water and land impact factors. Typically, these "FLW times impact" pairings are done by food category (sometimes by geographical location), and then summed together to arrive at carbon, water, or land footprints. The impact factors themselves are calculated using life-cycle assessment (LCA). LCA is a methodology used to assess the environmental impacts of a product, process or activity throughout its life cycle, from the extraction of raw materials to processing and transport. However, because the primary production is predominant in terms of land and water use, other stages are often overlooked and are focused on less (WRAP 2011; FAO 2013). This approach allows for prioritizing between different types of food. The main downsides are the data gaps for specific food products produced in specific locations and using specific practices. Proxy data are often used to fill in gaps.

Combining product carbon footprints with food waste volume data requires careful analysis. This is because the two types of information are often calculated with for different purposes. For example, it would be incorrect to apply impact factors relating only to the edible fraction of FLW to total FLW that includes edible and inedible parts.

It is also important to work with impact factors calculated for the correct stage of the supply chain, matching the exit point of the material from the food supply chain. For example, if food is wasted at the manufacturing stage, it is incorrect to multiply this weight of FLW by the full life-cycle impact factor that also includes the use phase (e.g., cooking and refrigeration at home), because the food material wasted by the manufacturer had not undergone cooking and refrigeration at home. Care should also be taken with the end-of-life stage that can be a part of food LCA; the LCA study could have taken different assumptions that do not match the situation that the FLW impact study is investigating. This is less problematic for water and land, as the impact factors typically only include primary production.

In summary, the components that contribute to the impact factor must to be understood, and probably adjusted, so that they are valid for wasted food, not for consumed food.

Table 30. Bottom-up Approach

Strengths	Limitations/points to consider
• **Allows prioritization between food types** • **Relatively detailed and disaggregated**	• Depends on data availability for impact factors y • Issues with matching activity and impact data

Types of Impact (Scope)

- Embedded impacts
- Direct impacts
- Waste management impacts

Embedded impacts are, from the perspective of one actor in the food supply chain, those that happened upstream. For example, for a food processor, these would be impacts associated with primary production, such as chemical use and water use in agriculture.

Direct (or added) impacts are, again from the perspective of an actor in the supply chain, those added by that actor themselves. For the example of the food processor, these include GHG emissions and energy and water use associated with handling food in the facility.

Waste management impacts are, for example, associated with transportation of FLW, further land use in the form of landfills, and additional methane emissions from landfill.

Wasted food (i.e., the edible fraction) is typically associated with all these impacts: the embedded impacts (those that occurred upstream in the food supply chain), direct impacts, and those associated with waste management. The inedible parts associated with food (also known as unavoidable food waste), such as peelings and bones, are typically associated with waste management impacts only, unless the inedible parts also have an economic value (e.g., orange peel used as cattle feed, bones used for bone meal). In those cases, some of the impacts would also be allocated to the inedible parts, relative to their economic value.

For example, a bakery can calculate the impacts associated with the bread wasted from its facility by estimating:

1. The embedded impacts associated with the flour and other ingredients that end up being wasted as parts of wasted products;
2. The impacts associated with energy and water use within their own facility, allocated for bread that is wasted; and
3. The volume of waste being sent away and the associated impacts relating to its management.

Table 31. Different Types of Environmental Impacts Associated with Wasted Food and Associated Inedible Parts

	Embedded impacts	Added impacts	Waste management impacts

	Embedded impacts	Added impacts	Waste management impacts
Wasted food (avoidable FW)	✓	✓	✓
Inedible parts associated with food (unavoidable FW)	✗	✗	✓

4.1.2 Greenhouse Gas Emissions (Carbon Footprint)

Different carbon footprint studies have taken different theoretical and methodological approaches.

GHG emission studies exist that estimate either the absolute impact of food waste or the benefits of a real or hypothetical change. Use of both the top-down and bottom-up approaches can be found in the literature.

The top-down approach uses the national sectoral emission accounts, which most countries tend to collect and report. The main shortfall of this approach is that it misses not only the nuances coming from the differences in wastage rates between different types of products, but also differences in carbon footprints between products. For example, wasting one tonne of beef meat has much larger implications than wasting one tonne of wheat, but the top-down approach assumes the same environmental impacts for each. It also does not provide granular data for, say, prioritization between different food categories.

The bottom-up approach (using products' LCA carbon footprints as the impact factors) involves taking the weight of wasted food for a set of different food categories (i.e., activity data) and multiplies this with products' carbon footprints (i.e., impact factors) sourced from the literature. Because of data constraints, most studies assume that the GHG emissions associated with growing the same crop in different countries are similar.

Carbon footprint is one component of LCA, which accounts for emissions of GHGs (in addition to carbon dioxide, there are methane, nitrous oxide and hydrofluorocarbons) expressed typically in the 100-year global warming potential equivalent of carbon dioxide. For more information on the general carbon footprint methodology, please refer to the following:

- ISO/TS 14067:2013 Greenhouse gases - Carbon footprint of products
- PAS 2050:2011 Specification for the assessment of the life-cycle greenhouse gas emissions of goods and services

As has been mentioned, emissions of greenhouse gases can be split between the embedded impacts (e.g., those that occurred in primary production) and waste management impacts; from the perspective of an actor in a supply chain, there are also the direct impacts they themselves add. In GHG protocol terminology, embedded and waste management impacts are both Scope III impacts, whereas the added impacts are either Scope I (related to own fuel use) or Scope II (related to electricity use). Some studies, such as the FAO study on global food losses and food waste (FAO 2013), include the embedded GHG emissions but not the waste management ones.

Those studies that focus on waste management impacts also tend to include an estimate of production impacts as a representation of the reduction option. For example, the waste reduction model (WARM), created by the US EPA, is a tool that estimates GHG reductions from several different waste management practices. WARM is also available as a tool based on a database developed in openLCA software, and version 14 matches the corresponding Excel version of WARM. The WARM model also includes upstream GHG factors, which can be revealed by exploring source reduction as an alternative scenario.

All the published studies use a few representative products, rather than attempt to provide separate estimates for hundreds of food products available to consumers in food markets.

Emissions added by individual actors in the supply chain (Scope I and II) can be estimated from the energy use in the facility; that is, by calculating the energy use per volume of all food processed by the facility and then calculating the share that is associated with wasted material. Energy use and other potential sources of GHG (e.g., refrigerant leakage) can be converted to GHG using publicly available emission factors.

Sources of Impact Factors

There are a few types of sources for GHG impact factors, including:

- Individual product LCA studies; for example, for a study on the synthesis of food waste data, the authors performed a comprehensive review and quality check of published product LCAs (WRAP 2011);
- Meta-studies that have also collected the factors for a wide range of food products (e.g., Clune et al. 2017) and for livestock products (DeVries and DeBoer 2010); and
- Commercial databases such as Ecoinvent, GaBi, FoodCarbonScope data (CleanMetrics no date), World Food LCA Database and Agri-Footprint; and
- The USDA National Agricultural Library's LCA Commons.

If the study is using an LCA tool, such as OpenLCA, GaBi or Simapro, using the factors embedded in those will be the easiest, as buying commercial data sets can save time. These can also be separated by supply chain stage, which may be necessary depending on the chosen methodology. Using the factors published in academic papers has the benefit of having no financial outlay but requires time to collate the relevant information and access to the academic journals.

The Provision Coalition's Food Loss and Waste toolkit contains GHG factors for several food types specific to Canada. These are split between three categories: embedded in ingredients, added during processing in a facility, and downstream/waste management. These are applied to the estimates of FLW.

Including Land Use Change Impacts

One component of life-cycle carbon footprints is land-use change emissions. Land-use change, such as the clearing of forests for use in agriculture, can greatly affect the exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In many situations, wasting food contributes to clearing of the forest, but it is difficult to estimate by how much and what assumptions to use. The land-use change component has often been excluded from the carbon footprint because of lack of data or uncertainty around the value. WRAP (2011) estimated that the inclusion of emissions associated with land use change would increase the average carbon footprint of avoidable food waste in the United Kingdom by about 20%, but other food and biofuel systems studies indicate this can be much higher if considering both direct and indirect land-use change. Given the above, it would be good practice to report figures with and without land use change.

Table 32. Including Land Use Change Impacts

Strengths	Limitations/points to consider
• **More comprehensive and complete assessment**	• Data availability and interpretation • Comparability with other studies that did not include land-use change

4.1.3 Water Footprint

There are fewer analyses of water footprints than GHG emissions of food waste. Most are done for the overall FLW and tend to use the bottom-up approach.

There are two methods used to assess the bottom-up water footprint of products and services:

- The older water footprint method proposed by the Water Footprint Network community
- A newer water-scarcity weighted water use method proposed by the LCA community. The newer method is also a subject of the International Organization for Standardization's water footprint standard ISO 14046:2014, *Environmental management—Water footprint—Principles, requirements and guidelines.*

The two methods are broadly similar and encompass the computation of water use and its impacts. The main differences are that the Water Footprint Network methodology distinguishes between "blue," "green" and "gray" water footprints,[17] whereas the ISO method uses only direct water use (equivalent to blue water) but multiplies it with a geographical water scarcity factor.

The Water Footprint Network provides country-specific blue-, green- and gray-water impact factors for crop and animal products.

The country scarcity factors for the ISO method can be found on the website of Water Use in Life Cycle Assessment (WULCA), a working group of the UN Environmental Programme–Society of Environmental Toxicology and Chemistry Life Cycle Initiative. Green and gray water are not included in water impacts as, in the LCA methodology, they are already included in the other more specialized indicators such as land use, toxicity or eutrophication impacts.

More information on the general water footprint methodology is available in a number of publications (Mekonnen and Hoekstra 2011) (Mekonnen and Hoekstra 2012) (Boulay et al. 2013) (Boulay 2016) and in standard ISO 14046:2014.

Summary of Methodologies Used in Existing Studies

All the reviewed food waste studies that calculated water impacts used the older Water Footprint Network method (Kummu et al. 2012, FAO 2013, WRAP 2011). Water footprint was calculated similarly to carbon footprint, taking the weight of food waste and multiplying with an impact factor.

[17] Blue water is water withdrawn from ground or surface water sources (e.g., irrigation water). Green water is water evaporated from soil moisture (e.g., rainfall). Gray water is the volume of water required to dilute polluted water before it can be safely returned into environment (Hoekstra et al. 2011).

The studies differ in their choice of blue and green water footprint; studies by FAO (2013) and Kummu (2012) only included the blue water footprint. The study by WRAP (2011) included both the blue and the green water footprint.

Inclusion of green water (water from precipitation that stays in the field as soil moisture) in water impacts is debated. Green water may also be scarce, and in the context of food waste it may represent an opportunity cost (i.e., it could be used for an alternative crop that might have significant economic or nutritional value). However, if agricultural land were to be replaced by natural vegetation, green water would evaporate naturally anyway. If food were not grown, green water would not necessarily be available for another human use or to support ecological flows in rivers (it would, however, support natural vegetation growth). The decision of whether to use green or blue water would normally depend on which one of these issues was predominant, and this is different at every location or catchment. Food waste studies, however, typically cover multiple locations; therefore, it is difficult to decide which, the blue or the green water footprint, is more appropriate to use.

The gray water footprint is not accounted for in any study; it is more conceptual and lacks data, for example, about the assimilation capacity of freshwater ecosystems.

Possible Limitations and Pitfalls

The main limitation of the water footprint methodologies relates to the importance of the location where water use occurs, the timing of water use (e.g., dry or rainy season) and scarcities at those locations and times of the year, but it is difficult to obtain data on water scarcity that is this specific.

There is to date no consensus on whether it is best practice to include the green water footprint alongside the blue water footprint. Similarly, whether to use the Water Footprint Network method or the new LCA scarcity-based approach is an open question. The advantage of the Water Footprint Network is the free availability of the data. The LCA-based approach also publishes scarcity factors, but water use by the crop is not as easily obtainable (although one could use the blue water footprint from Water Footprint Network for this purpose).

Whichever method is chosen, it should be clearly communicated along with any impact result. This is challenging; members of the public have an interest in issues such as water use but would are often not familiar with concepts such as blue and green water use.

4.1.4 Land Use (Direct and Indirect)

It is useful to understand what amount of land is associated with the production of food that is ultimately wasted. This land use is usually dominated by agricultural production and it can be calculated using yield statistics. Some livestock production systems used for animal food products use both pasture and arable land area (to grow livestock feed). One aspect to be careful about is multiple cropping (where several crops are harvested from a particular area of land in a year), and crops that have multiple-year cycles (e.g., sugar cane).

Two studies in this review included land use impacts of food waste: a study of global food losses and food waste (FAO 2013) and a study of food supply chain losses and their effects on freshwater, cropland and fertilizer use (Kummu et al. 2012). The latter study included only cropland (not pastureland).

The most commonly used sources for land use are crop- and country-specific harvested areas or yields (in tonne per hectare) from the FAOSTAT database (FAO 2018a). For livestock, the main source is a published study (DeVries et al. 2010).

No studies were found to estimate the land use associated with landfill space required or saved, which is a shortfall given that the scarcity of landfill capacity can be a strong local driver for reduction in food waste and is also a concept well understood by the public.

The other limitation is that the land use metric alone does not indicate the quality of the land that is occupied—the land could be marginal and therefore have few alternative uses or could be very productive and have many alternative uses. There are some examples where this has been done for food in general; for example, one study shows global agricultural land distribution according to land suitability and the natural climax vegetation displaced by agriculture (Bajželj et al. 2014).

The ecological footprint (Global Footprint Network 2018) methodology also takes an interesting approach by converting a land area in hectares or acres to "global hectares" or "global acres"— that is, to units of land of global average productivity (e.g., using one hectare of land of double than average productivity would count as using two global hectares, noting that the baseline productivity equivalence factor of cropland is 2.51). Another alternative to using land use categories is using net primary productivity (the economical productivity of land) as a proxy (see Bajželj et al. 2014 and Alexander et al. 2017 for global assessments). These take both land area and its productivity into account but are less readily understandable outside ecology studies.

Land use as a metric does not indicate if the land occupation is beneficial or negative for the environment, particularly regarding impacts on soil quality. Conversion from natural vegetation to arable land typically results in loss of soil in general and loss of soil organic carbon (which is a good indicator of soil quality) in particular. This process often continues under conventional farming, while some specific practices such as conservation agriculture (no-till agriculture), organic farming and well-managed grasslands (Garnett et al. 2017) can reverse this process and improve soil quantity and quality. No study has been found that would consider how FLW relates to this, or what would happen if the quantity or management of FLW were to change significantly.

Land use metrics, along with the biodiversity metrics covered later, are in the process of being developed so that they best represent land as a resource in all its complexity. Land use is inherently interlinked with the land-use change component of carbon footprint, green-water footprint and biodiversity studies, and there is no consensus yet on which methods to use.

4.1.5 Chemical Inputs

Only one of the reviewed studies estimated chemical inputs (fertilizer use) associated with wasted food (Kummu et al., 2012). There are no studies looking at pesticide, herbicide and other chemical use.

In the one reviewed study, researchers calculated fertilizer use related to FLW using region-specific food wastages for basic food commodities and country-specific fertilizer use from the FAOSTAT database (Kummu et al. 2012). They summed the use of nitrogen, diphosphorus pentoxide and potassium oxide as total fertilizer. However, as figures on fertilizer use are only available per country, they assume that the fertilizers were equally distributed over the entire harvested cropland (top-down approach).

An alternative approach that could also potentially allow inclusion of other chemicals would be to look at data collected on chemical use as a part of life-cycle inventories for some representative crops and use a bottom-up approach (LCA databases are listed in Section 4.1.2 Greenhouse Gas Emissions (Carbon Footprint)].

4.1.6 Energy Use

Energy is used throughout the food supply chain; for example, it is used in diesel-powered tractors, electric irrigation pumps and fertilizers and pesticides production activities using natural gas and petroleum. Webber (2012) asserts that for each unit of food energy produced, 10 units of energy are generally spent to grow and process it.

From the reviewed studies, only one considered the energy embedded in FLW (Cuellar and Webber, 2010). The study combined the bottom-up and top-down approaches to match the energy intensity of different types of foods with the total energy used by different stages of the food supply chain in the United States and the food wastage rates data. The analysis suggested that energy embedded in wasted food (at the consumer stage) represents approximately 2% of the annual energy consumption of the United States, which is more than the energy-saving potential of many popular efficiency strategies.

Outside FLW impact studies, energy use and GHG emissions are often analyzed together because energy is such an important contributor to GHG emissions. Calculations of embedded energy follow similar steps and data sources the calculation of an embedded carbon footprint.

From the point of view of a food business, it may be more interesting to track energy use associated with wasted food separately, including that which is added by the facilities such businesses operate themselves in the form of energy use and natural gas. Toolkits such as that provided by the Provision Coalition can support this in a user-friendly way.

4.1.7 Biodiversity Loss

The loss of biodiversity is happening at unprecedented rates and is one of the key threats to global sustainability. Food production is the number-one driver of biodiversity loss through conversion of natural habitats to farmland, intensification of farming, creation of pollution and, in the case of fish, overexploitation (Rockström et al. 2009). For example, agriculture is estimated to be the proximate driver for between 60% and 80% of deforestation worldwide (Kissinger et al. 2012). By extension, some of this biodiversity loss occurs to produce food that is wasted.

Biodiversity loss is a complex concept that encompasses the declines of many individual species and ecosystems. Thus far, there is no satisfactory single metric (impact factor) that would encompass this complexity.

Only one of the reviewed studies (FAO 2013) attempted to assess the impact of food waste on biodiversity. It deployed qualitative and semiquantitative approaches, working through several of the following proxies:

- Effect on deforestation (and therefore land use; this is a good proxy for land-based biodiversity loss);
- Impact on the International Union for Conservation of Nature (IUCN) Red List of critically endangered, endangered and vulnerable species of mammals, birds and amphibians (IUCN 2018); and
- Impact on the Marine Trophic Index (Biodiversity Indicators Partnership 2018), which measures the decline in abundance and diversity of fish high in the food chain (important for assessing impacts of fish waste, such as the by-catch on fisheries).

Land use and land productivity (e.g., net primary productivity) can also be used as proxies for biodiversity impacts of food production; for example, clearing natural habitats, notably forests, is seen as the primary vector of food production’s effects on biodiversity.

The field of assessing the impacts of food production on biodiversity is rapidly evolving. Some recent studies, such as that by Chaudharya and Kastner (2016), offer modeled projected species loss per tonne of food produced for 170 crops in 184 countries.

4.1.8 Other Impact Categories That Could Be Applicable to FLW

There are other categories of impact; for example, eutrophication and acidification potentials are sometimes included in (full) life-cycle assessments of food products, but are not yet calculated specifically for FLW.

A few existing methodologies are trying to combine several impacts into one metric. These could also be applied to FLW, but no studies that would do so have yet been found. Natural capital accounting, for example, is gaining much traction with large food businesses. It is possible to estimate FLW costs using natural capital accounting by following the same steps as for carbon, water use, water pollution, land use and waste management, and then adding a step: assign a monetary value to all impacts and resource dependencies (Natural Capital Coalition 2016). This can help with communicating and presenting the business case for food loss and waste reduction.

Another combined metric not yet applied specifically to food waste is the ecological footprint (Global Footprint Network 2018). The ecological footprint measures the ecological assets required to support human consumption, including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure and for absorption of its waste, especially carbon emissions. One could therefore calculate what part of an ecological footprint is caused by wasted food.

4.1.9 Summary: Environmental impacts

For environmental metrics such as carbon and the water footprint, the impact of FLW has been estimated numerous times and is underpinned by well-developed frameworks (e.g., life-cycle analysis). There remain some important questions when making such estimates that can materially influence the results. In the case of GHG emissions, these questions include whether to include the emissions associated with the change in land use caused by food production. For water footprints, whether to include green water along with blue water or move to a scarcity-weighted method is still being discussed.

Other environmental indicators— land use, chemical use, energy use and biodiversity loss—have been estimated less frequently for FLW. Examples are given where they exist, but these emergent areas of research are likely to develop over the next few years.

For all environmental impacts, appropriate calculation boundaries should be used, reflecting the type of information being sought. It is good practice to describe the nature of any comparisons being made and the implicit assumptions being made in the calculations, including the counterfactual assumptions. This helps to ensure that the information is used most appropriately when important decisions are being made.

No environmental impact assessment method can arrive at one “true” value. The method, and therefore results, depend on the intended purpose of the study and framing of the research question. Environmental information estimated by these methods is used to make claims of positive impact by organizations, to benchmark, to identify hot spots and prioritize efforts, or simply to highlight the magnitude of the issue. For the interpretation of the results, it is important to be aware of the assumed counterfactual scenario and of which types of waste and life-cycle stages are included. If there are differences in those, individual studies will come to different figures for the same food item even if the material and processes involved are similar. However, current methods are deemed to be sufficiently accurate for most decision-making purposes.

Table 33 summarizes the FLW environmental impact studies reviewed for this technical report, according to the impacts covered and the theoretical and methodological approaches that were taken. No existing studies were found that would cover Mexico.

Table 33. Summary of Key References for Estimating Environmental Impacts

Geography	Author, year	Title	Theoretical approach	Methodological approach	Impacts included
Canada	Provision Coalition	Provision Coalition's Food Loss and Waste toolkit	Benefits of change	Bottom up (LCA)	Carbon footprint
United States	Venkat 2012	Climate change and economic impacts of food waste in the United States	Overall impacts	Bottom up (LCA)	Carbon footprint
United States	EPA	WARM tool	Benefits of change	Bottom up (LCA)	Carbon footprint
United States	Cuellar and Webber 2010	Wasted food, wasted energy: the embedded energy in food waste in the United States	Overall impacts	Combination of bottom-up and top-down approaches	Embedded energy
Global	Jan et al. 2013	Food wastage footprint—impacts on natural resources	Overall impacts	Bottom up (LCA)	Carbon footprint Water footprint (blue) Land use Biodiversity
Global	Kummu et al. 2012	Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland and fertiliser use	Overall impacts	Bottom up (LCA), Top down for fertilizer use	Water footprint (blue) Land use (cropland) Fertilizers
European Union	FUSIONS	Criteria for and baseline assessment of environmental and socio-economic impacts of food waste	Overall impacts	Bottom up and top down	Carbon footprint
United Kingdom	WRAP and WWF, 2011 (Ashok Chapagain and Keith James)	The water and carbon footprint of household food and drink waste in the UK	Overall impacts	Bottom up and top down	Carbon footprint Water footprint (green and blue)

Geography	Author, year	Title	Theoretical approach	Methodological approach	Impacts included
United Kingdom	Salemdeeb et al. 2017	A holistic approach to the environmental evaluation of food waste prevention	Benefits of change (including rebound effect)	Bottom up	Carbon footprint
United Kingdom	Moult et al., 2018	Greenhouse gas emissions of food waste disposal options for UK retailers	Benefits of change	Bottom up	Carbon footprint
Japan	Matsuda et al. 2012	Life-cycle greenhouse gas inventory analysis of household waste management and food waste reduction activities in Kyoto, Japan	Benefits of change	Bottom up	Carbon footprint

4.2 Financial Impacts

A key aspect to consider is the financial impact of FLW on businesses along the supply chain, as well as on people as consumers of food. How to assess the cost of FLW varies depending on the aims of the organization. This includes decisions on the level of detail to go into, which costs to include, and the specific calculations and data sources. For instance, the requirements for a government's assessment of the financial impacts of FLW on society will be different from those of a business deciding whether FLW-reduction interventions will yield a positive return on investment.

This section examines:

- How to assess the market value of FLW for segments of the food supply chain (e.g., retailer supply chain, restaurants);
- The use of retail prices to assess the market value of FLW;
- How to assess the market value of FLW at an individual business level;
- The disposal costs of FLW at an individual level; and
- The costs of FLW more widely.

Some studies go beyond the quantification of market value and disposal costs. This section additionally highlights a few examples, including the approach from the FAO, using social accounting matrices and marginal cost abatement curves to do so. For a discussion of rebound impacts, see Section 4.1.

4.2.1 Market Value of FLW Across Segments of the Food Supply Chain

Table 34 summarizes the approach taken in a recent report in Canada FLW (VCMI 2018) for each segment of the supply chain. The report notes that it is important to identify all the relevant sectors and all relevant areas for which FLW needs to be quantified and valued, including, for instance, FLW for the international hospitality sector, such as airlines and cruises, and FLW for institutions such as hospitals, schools and prisons, as well as, say, seafood, including catch and processing.

The valuation of food waste can require a pragmatic approach to make the best use of the data available and that the appropriateness of simplifying assumptions should be assessed relative to the degree of precision needed.

Table 34. Approach Taken in a 2014 VCMI Report on Canadian FLW for Each Segment of the Supply Chain

Value chain segment	Methodology to estimate the cost of FLW
From field to retailers (including field, processing/packaging stage and transportation/distribution)	• % FLW * sales of agricultural and seafood products • Works by considering the waste at the field, processing/packaging stage and transportation/distribution stages as lost sales. Industry advised on the (unrecovered) % of FLW across these stages. • Average % FLW * (billions of Canadian dollars of sales of agricultural products + billions of dollars of sales of seafood products) • Sales data sourced from Statistics Canada and Agriculture and Agri-Food Canada
Restaurants	• % FLW * spend on food at restaurants • The report estimates 10% FLW at restaurants. • Average household expenditures on food purchased from restaurants in Canada (from official statistics) * number of households in Canada *10% (of FLW) = C$ of FLW at restaurants
International catering (airlines, cruise ships, merchant ships, yachts, and so on)	• Not enough separate data for airlines. Number of wasted meals * cost of each meal • The number of wasted meals was calculated from the number of passengers (23.6 million) and by making assumptions about the number of meals served per passenger (two) and the percentage that could be saved (10%); then multiplying by the assumed cost of each meal and service (C$10), yielding an estimate of the value of wasted meals on international flights of C$47 million.
In the home	• FLW weight * cheapest retail price for food and drink • This has been estimated in Canada by multiplying estimates of the quantity of solid food and liquids wasted per person (183 kilograms and 84.6 liters) by the price per kilogram or liter of the cheapest solid food and liquid (C$2 per kg and $0.5 per liter * the population (35.5 million) = an estimate of the minimum value of FLW from retail to plate (C$14.5 billion)
In institutions (hospitals, schools, care facilities, prisons, and so on)	• Not included in the calculation but believed to be significant (Buzby and Guthrie 2002)
Retail	• Confidential industry statistics

4.2.2 Using Retail Prices to Estimate the Cost of Household FLW

The approach above uses the lowest retail price per kilogram of food to estimate the minimum value of FLW (in the home). Other approaches are possible to estimate the value of consumer food waste, depending on data availability and the desired degree of precision of the estimates. In the United Kingdom, for instance, WRAP (2013d) estimated the cost of household food waste by multiplying detailed estimates of avoidable food waste at the product level by detailed estimates of retail prices. This required detailed information about the types of food wasted, and a method for linking these categories of waste to information about food purchases.

A common source for retail prices might be supermarket websites or grocery-comparison websites; alternatively, it is possible to purchase proprietary data, such as Nielsen Homescan data or data from the IRI Consumer Network. There are disadvantages to doing this. WRAP (2013d) notes that:

> … the average prices used do not take into account the market share of different products within a food type. As a simple example, a product range may include standard (cheaper) and premium (more expensive) versions of a product; if one of these two products is sold in much higher quantities than the other, then taking a simple average of the two prices leads to a distortion in the price of the waste. Specific sales data to take a weighted average based on sales would be very expensive to purchase and time-consuming to perform the analysis.

In some countries, an alternative source would be government-produced household food purchase statistics. These often include the weight and price of a range of food purchases by households. These allow (weighted) average prices by product type to be calculated, reflecting the different mix of (say, standard versus premium) products within a food type.

Prices taken from supermarket websites can be used to supplement the government survey data, or as an alternative in their absence. Food price inflation figures (using the consumer price index from the office for national statistics) can be used to inflate the latest survey data to the same period as the waste estimates.

This yields a price per unit weight of product (e.g., per kilogram), which is then multiplied by the corresponding weight of food waste to yield estimates of the value of the food waste.

Strengths	Limitations/points to consider
• **Relatively cost-effective way of obtaining financial cost information** • **Provides information for different types of food, useful for prioritization and in campaigns.**	• Requires government estimates of food purchases to exist • Requires detailed food waste statistics • Requires matching of food-waste and food-purchase categories • Only as strong as the government data set; e.g., methodological issues pertaining to diaries or surveys may influence results

If there is no detailed information on the types of food wasted, an alternative approach is to estimate the average cost of food purchases across all foods. This can be achieved by taking government food-purchase data and dividing the total monetary value of food purchased by the weight of purchases. This will give an average cost per unit weight (e.g., dollars per kilogram, dollars per pound), taking into account the different foods purchased and the different costs within a food category (e.g., reflecting standard versus premium). This method is much simpler and quicker than that mentioned above, but less accurate with less granular data.

Strengths	Limitations/points to consider
• **Cost-effective method** • **Quick to apply**	• No data by different types of food • Less accurate, especially if average cost of foods wasted differ from average cost of foods purchased

4.2.3 Using Retail Prices to Estimate the Cost of FLW Across the Supply Chain

Retail prices are used to estimate the cost of FLW, not just for households but also other segments of the supply chain. For instance, a 2011 paper in the *International Journal of Food System Dynamics* (Venkat 2011) estimates the economic cost of waste across various stages of the supply chain using retail prices. Retail prices were used because

> … the retail price of a commodity reflects all the value added throughout the value chain—including agriculture, processing, packaging, distribution and retail—and provides a very good measure of the total economic value embedded in the commodity as delivered to consumers. Therefore, retail prices are used to uniformly calculate the economic impact of all avoidable food waste occurring after the production/processing stages—specifically waste at the distribution, retail and consumer levels.

In this case, the paper sources prices for food commodities from the USDA, filling data gaps with prices from a major online retailer. The quantity of avoidable food waste is estimated at the distribution, retail and consumer levels (using the loss-adjusted food availability data from the USDA) and multiplied by the corresponding retail prices.

Another example is the approach from the USDA (Buzby et al. 2014), which estimates the value of FLW by quantifying the edible amount wasted post-harvest (not including farm and farm-to-retail waste) and multiplying by the value of foods as purchased at retail prices, for some 200 individual foods. The USDA valuation includes identifying individual food commodities, as defined in the loss-adjusted food availability data from the USDA Economic Research Service; estimating national average retail prices for each individual commodity (and inflating prices to the correct year where only older prices were available); carrying out some data validation; and then multiplying the estimated price by the food loss estimates (available as amounts per capita, multiplied by the US population to yield total food waste) for each type of commodity. Here, the retail prices are calculated from scaled-up consumer panel data (Nielsen Homescan), where members of the panel report the quantity of each food they buy and the prices they pay for food consumed at home. This method of estimating the price for each food is described in a 2012 report as “an intricate and time-consuming process, particularly because we had to identify and select products to price that were representative of typical consumption by Americans” (Buzby et al. 2012, 561–570). The Homescan data are used together with projection factors to caclulate estimates of the total amount spent on and the total quantity bought of each food by all US households. For each food, the total amount spent in a year is then divided by the quantity sold to give an average price. For example, the data showed that Americans spent US$4.074 billion in 2008 on 9.89 billion pounds of unflavored 2% refrigerated fluid milk, yielding a price of US$0.41 per pound. Some foods, such as canned fish, require conversion from canned solids to a drained weight. A 2011 report further explained that a few products were poorly represented in the 2008 Homescan data and required supplementary data and calculations (Buzby et al. 2011, 492–515).

The World Bank (internal document, 2017) estimates the economic cost of food waste by taking the perspective of lost income (i.e., capturing the value of the FLW if retailers had been able to sell the wasted food at market prices).

Strengths	Limitations/points to consider
• **Cost-effective method** • **Data publicly available in many countries**	• Requires matching of food-waste and food-purchase categories • Only as strong as the data used; some inaccuracies will be present in most data sets

4.2.4 Market Value of FLW for Individual Businesses

Quantifying the costs for businesses might typically involve working out:

- The purchasing costs of the incoming food or ingredients;
- The costs added to the food within the business (e.g., relating to labor or utilities); and
- The costs associated with the disposal, treatment or redistribution of FLW or food surplus.

There are tools in the public domain as well as many private organizations that offer services to quantify and value FLW. The above three categories reflect those found in the Provision Coalition's *Food Waste Reduction and Best Practices Toolkit* (developed in partnership with Enviro-Stewards). This tool, aimed at manufacturers and processors, uses financial information provided by the user (e.g., on the cost of ingredients and products), the destinations to which the wasted food goes, and estimates of the quantities of food wasted in different stages within a manufacturing process. The toolkit also estimates environmental impacts, again divided between these three cost types.

In addition, the US EPA provides a food waste management tool (EPA 2016b) that can be used to value FLW for businesses based on the purchasing cost of the food that ends up wasted. This tool can also be used to calculate, based on company specific input data, the costs of disposal as well as the cost of alternatives (donating, composting), taking into account any additional costs (e.g., the costs involved in separating the FLW, such as liner bags and staff training).

Depending on data availability and the desired degree of precision, it is worth considering how well the purchasing cost used in the calculation can reflect the composition of the food waste. For instance, if a business buys a mix of expensive meats and cheaper bread to make sandwiches and mostly bread is wasted, the purchasing cost used to estimate the value of FLW should ideally reflect this. An average purchasing cost, weighted by the respective amounts wasted, would provide a more representative estimate than a simple average.

For an even more comprehensive estimate, it may be possible to include the costs incurred (labor, utilities and so on) across the entire organization, whether these costs are directly or indirectly associated with the actual handling of the food. A report on Canadian FLW (VCMI 2014) notes that:

> Businesses cannot experience food waste without incurring associated costs. Capital investments in infrastructure and inventory, labor across the entire organization (not just in the processing facility, store, or distribution center), energy, financial charges and reconciling accounts, disposal fees, price markdowns, repackaging, transportation, equipment wear and tear—these are just some of the supplementary costs associated with food waste that impact business profitability.

For example, in a recent report by WRAP and WRI, *The Business Case for Reducing Food Loss and Waste* (Hanson and Mitchell 2017), the authors were able to access and to analyze financial cost and benefit data for nearly 1,200 business sites across 17 countries and more than 700 companies in various food sectors that had undertaken FLW prevention initiatives. They found that the median benefit–cost ratio for these initiatives was 14:1 (i.e., "for every US$1 (or other relevant currency) invested in FLW reduction, the median company site realized a US$14 return").The benefits of reducing FLW included optimized food or raw material purchased, lower waste collection and waste management costs, reduced disposal fees, more revenue from greater food sales and more. This was balanced against the costs of taking action (staff costs, consultants, equipment, process redesign, and so on).

Businesses may also take account of the nonfinancial impact of their FLW management. For instance, members of the board may view as important the business's contribution to society (e.g., helping to feed the hungry, doing something good for the environment) if it is congruent with the business's purpose, mission and values, or if they see it as valuable from a brand point of view.

Spoiler Alert offers a *Strategic Guide for Using Data* to drive food loss and waste reductions (Spoiler Alert 2017). Spoiler Alert is a software company that helps food businesses manage unsold inventory and provides a "cloud-based reporting and analytics platform aligned to the FLW Standard, enabling the real-time tracking of unsold inventory and organic waste" (Spoiler Alert 2017). Keeping track of the value of amounts landfilled, donated or diverted to animal feed can help to maximize the return on investment of food waste reduction initiatives, in particular the choice of how to handle unsold inventory. Comparing options might reveal opportunities to improve profitability (this part of the guide focuses on how to reduce financial losses from unsold inventory and so does not include waste prevention in the comparison). For instance, in the United States, donations of unsold food inventory to qualified organizations entitles businesses to tax deductions. This means, for instance, that the financial savings from donating the food surplus can be larger than the revenue from selling at a discount.

The profit margin (after tax) can then be compared across options. The disposal option generates a disposal cost and offers no tax relief and no income. The donation option dispenses with the disposal cost and offers tax relief but no income. The liquidation option (i.e., selling surplus to a closeout buyer) dispenses with the disposal cost and offers income but no tax relief (and taxable income is higher). It is possible then to work out the tipping-point liquidation price, that is, the price at which the value from liquidation is the same as the value from donating. Beyond that price, there is an incentive for the company to liquidate its surplus food. This approach has to consider any additional costs associated with the various options (transport, separation, and so on).

A 2016 ReFED report noted that in 2015 the US Congress signed a tax-break package that extended the eligibility for food-inventory-enhanced tax deductions previously only available to large corporations to a wider array of businesses:

> Under the previous standard food donation deduction, a business could only claim the cost basis of donated inventory. An enhanced deduction passed in this legislation allows businesses to claim both the cost basis and half of potential profits if the inventory could be sold at fair market value …. Tax incentives, whether in the form of credits or deductions, induce farms, retailers, restaurants, and foodservice providers to undertake the behavioral and operational changes needed to donate additional food instead of sending it to disposal. It is expected that the tax benefits will roughly equal the incremental costs of donation, leading to a net breakeven financial impact for businesses … There is a lack of data regarding the portion of food donors that receive tax incentives today … [However,] anecdotal evidence from ReFED interviews suggests that a large portion of businesses may not go through the effort of claiming small tax benefits after donating, which could significantly reduce the net cost of this solution.

A 2016 Harvard Food Law and Policy Clinic report (Broad et al. 2016) has also pointed out that "Fear of liability often drives reticence to donate safe, wholesome food. Food donation is a voluntary act and would-be donors will usually opt for disposal or composting in the face of uncertainty about their liability risk." There is a provision to that effect in the 1996 Bill Emerson Good Samaritan Food Donation Act, which provides some liability protection for food donations made in good faith.

When calculating estimates of FLW for the wider economy, disposal costs are not always included. For instance, a 2011 paper (Venkat 2011, 431–446) estimates the economic cost of FLW and includes the market value (based on retail prices) but not disposal costs. The rationale is that

> … most of the food waste is generally landfilled, as assumed in this study. The typical cost structure for municipal solid waste collection and disposal in North America is a flat rate for a fixed volume of waste (Rosenberg 1996), which makes it difficult to quantify the real disposal

cost of a marginal increase or decrease in the quantity disposed. Therefore, disposal cost is excluded from our calculation of the economic impact of food waste. It should also be noted that disposal costs are likely to be negligible compared to the retail prices of the wasted quantities.

Depending on the data available, in particular on the breakdown of the disposal routes for food waste (e.g. landfill, composting, incineration) and the cost (gate fee) for each route, it may nevertheless be possible to derive economy-wide estimates for the cost of disposal of FLW. It is indeed possible, and perhaps likely, that this impact may be dwarfed, at the economy-wide level, by the market value impact, given the level of retail prices.

4.2.5 Economy-Wide Approaches

In some cases, for instance when considering the merits or otherwise of government intervention, a wider set of costs and benefits can be taken into consideration, such as social and environmental impacts. Some of these will not have a market price and can therefore be more difficult to value in monetary terms, but it can nevertheless be important to assess them as accurately as possible.

For instance, once the GHG emissions impact has been calculated in a common unit, such as equivalent tonnes of carbon dioxide (see Section 4.1), the monetary value of the environmental impact can be estimated using a so-called social cost of carbon. National government appraisal guidelines may indicate which value to use for the cost of carbon (e.g., traded and non-traded, domestic emissions and non-domestic emissions). Similarly, national government appraisal guidelines may provide guidance on which benefits and costs to include. For instance, social costs and benefits can in some cases be assessed (e.g., willingness to pay, time saved or spent) but guidelines may help draw the line at what is not feasible or not practical or not proportional to value. Even then, it may be possible (and advisable) at least to describe the impact, who is affected, possibly the direction of the impact, and so on. It is worth noting that these broader approaches might yield different estimates and different conclusions from approaches that focus on a narrower set of impacts.

There are several examples of different types of approaches to do this. The boundaries, level of detail and effort required must be assessed in relation to the purpose at hand.

A report by the FAO (2014) put a value, in US dollars, on a range of environmental impacts from FLW including GHG emissions, increased water scarcity, biodiversity risks, health effects caused by pesticide exposure, and soil erosion and its corollaries—an increased risk of conflict and loss of livelihood. The FAO was careful to highlight that the results “must be treated with a degree of caution as the calculation of non-market environmental and social costs of food wastage on a global scale requires a number of strong assumptions,” although it also pointed out that the lack of suitable methodologies most likely means that the findings constitute an underestimation, because many impacts cannot be included. The methodology is based on full-cost accounting of FLW. Ideally this might be done in a general equilibrium model with the full costs of FLW calculated as “the difference between the aggregate net welfare in society … derived from the current food system … and the aggregate net welfare from a hypothetical food system with less food wastage,” which takes into account the “fact that a zero-food-wastage world is not socially optimal in economic terms, while a lower but positive level of food wastage is.” However, crucial data are missing to be able to do that, so the FAO approach provides a (linear) approximation across a wide range of impacts.

Natural capital accounting, which puts a financial value to the benefits received from natural assets such as geology, soil, air, water and living organisms, has gained traction in recent years in some countries and various measurement methods are emerging, both at country level and for firms. For instance, the Cambridge Institute for Sustainability Leadership[18] is developing a framework for businesses to factor natural capital considerations into their business strategies. The proposed metric takes account of biodiversity and soil and water impacts.

A different take on this is to look at the economic value created when food waste is diverted from the waste stream. A 2016 EPA report (2016a) developed a waste input–output model to estimate the impact on jobs, wages and tax revenues of the recovery and recycling of a range of materials such as paper, metals, glass and food. In the case of food, "recycling" means the delivery of food to people in need, as well as the "use in producing minimally processed animal feed, rendering and animal by-product processing, biofuels manufacturing, anaerobic digestion, compost manufacturing and landscape material application." For each of these, the model uses data on waste flows (including volumes, recycling statistics, recyclable proportions, distribution of recyclables), employment and wage data, and corporate tax data to work out the different impacts.

Another tool involves using social accounting matrices (Campoy-Muñoz et al. 2017). This study highlighted that FLW studies focus mostly on the measurement of FLW itself, to a lesser extent on estimating the monetary value of the food wasted and, to an even lesser extent, on putting a value to the social and environmental costs associated with the FLW. In many cases, FLW is mainly valued based on how much it cost to produce and how much it cost to buy.

Some studies might extend the analysis to estimate how much society might be prepared to pay to avoid the social and environmental costs of FLW (and the missed opportunity to make something else with the resources used on the ultimately wasted food). However, the paper argues that this analysis needs to take into account "the interactions between actors and sectors in the food system and in the entire economy."

The approach by Campoy-Muñoz et al. involves a "multiplier model … developed using a social accounting matrix (SAM) with highly disaggregated agricultural and food industry accounts data (AgroSAMs)," which the paper argues provides a richer basis compared with other data sets used in other comparative general equilibrium models. The mathematics and the tools proposed to do this are arguably more complex than can be usefully described here, but it is worth considering some of the concluding remarks from the work.

The proposed modeling approach, instead of only calculating the monetary value of FLW in production value or retail value terms, can be used to assess the impact that a reduction in FLW might have on production, GDP and employment, considering the structure of the economy. It can also be used to compare impacts across countries, which might be useful for policy design, to tailor measures to the specific structure of the economy.

Strengths	Limitations/points to consider
• **Provides information on a range of important macroeconomic factors** • **Underpins business case at national or state/province level**	• Requires specialist calculations

[18] University of Cambridge Institute for Sustainability Leadership. Healthy ecosystem metric framework: biodiversity impact. Available online: <https://www.cisl.cam.ac.uk/resources/publication-pdfs/healthy-ecosystem-metric-framework.pdf>.

Another tool that comes up in assessing the financial impact of FLW, or more precisely the impact of FLW interventions, is the marginal abatement cost curve.

A report by ReFED (2016) uses a marginal food waste abatement cost curve to rank potential interventions by economic value and landfill diversion potential and takes account of profit potential and nonfinancial impacts. The marginal abatement cost curve approach produces a visual representation, across interventions, of how much FLW might be diverted compared with the economic value of each intervention, where an intervention might be, for example, standardized date labeling or donation matching software.

An economic model calculates the potential to reduce food waste by stakeholder and by product, the costs of making changes, the cost savings from reducing food waste and the new revenue opportunities. Based on this, the model estimates several metrics, including the economic value of each intervention, the business profit potential, and so on.

The paper finds that the value from prevention and recovery is much higher than the value from recycling food scraps: edible food purchased at retail is valued at US$1.34 per kilogram (US$5,143.60 per tonne), whereas the value has dropped to less than US$90.72 per tonne when the food is ready to be thrown away as scraps (where the value represents the avoided disposal fee and the sale of energy and compost).

The report notes that some interventions create benefits directly for businesses (e.g., trayless dining, which reduces food purchase costs). Others have wider benefits but may not present profit opportunities for businesses. For instance, tax incentives are typically necessary to stimulate food donations (including through food banks) that benefit consumers. Others still have benefits for both businesses and consumers (e.g., spoilage prevention packaging).

Strengths	Limitations/points to consider
• **Marginal abatement cost curve approach allows different policies and interventions to be compared** • **Supports prioritization exercises**	• Requires detailed information, including the effectiveness of interventions; few studies have measured these impacts, so the MACC approach relies on many assumptions and depends on the appropriateness of these assumptions.

4.2.6 Summary: Financial Impacts

This section describes a wide spectrum of complexity that can be used to estimate the financial impacts of FLW and food surplus. This section also highlights that the financial calculations undertaken by individual businesses may differ from organizations focusing on the wider economy (e.g., governments, NGOs).

At the simpler end of the spectrum, calculations involve multiplying the weight of FLW by the cost per unit weight (e.g., Mexican pesos per tonne). The factors used can take into account a range of costs, waste management costs, cost of the ingredients, embedded costs added in that supply chain stage (e.g., electricity, natural gas, labor). In some analyses, wider (less direct costs) have been included, such as the cost of employee time relating to food items being returned from a retailer to a manufacturer.

The choice of the type of factor to use is very important and should reflect the reason for estimating the financial impact. For example, if the financial impact of FLW prevention is being assessed, it is important to include all the costs that could be saved if the food doesn't get wasted. This will allow a better comparison with the costs of preventing that waste (e.g., investment in equipment, increased staff costs). Using only waste management costs can greatly underestimate the total cost to a company of wasting food and disguise the potentially much more lucrative opportunities of waste prevention upstream of waste management cost saving.

It is also important for businesses to take into account the cost of acting and, where relevant, to compare options. Options include upstream waste prevention as well as waste management options. Various tools are available for free (some are mentioned in this report) and there are companies that provide these calculations as a paid service. Some businesses may also want to consider taking into account environmental and social impacts, drawing from natural capital accounting or other approaches, as part of their business ethics or as part of sustaining their brand.

More complex analyses exist that examine the impact of diverting or preventing FLW, considering how an economy may adjust in response to these changes. Existing studies analyze the rebound effect and interactions between food sectors in the economy. These studies are currently few in number and the estimates they contain are likely to be approximate. Nevertheless, they could help to inform policy makers of some of the indirect consequences of tackling food waste, including impacts on spending, GDP and jobs, even if the exact scale of these effects is unknown.

For these economy-wide (or wider) assessments, there are typically national government guidelines on impact assessment that may have to be followed to standardize the approach taken. These might recommend that all impacts be considered and that impacts be quantified wherever feasible. Again, there is an element of proportionality to this. Financial impacts are typically included across all affected economic agents (citizens, businesses, and so on) and this report provides a few examples of avenues to pursue to calculate these. Environmental and social impacts are now also increasingly quantified and, where possible, monetized.

4.3 Social and Other Impacts

In addition to environmental and financial impacts of FLW and food surplus, there are social and other impacts that have been quantified to date. These are discussed in this section and include estimating the nutritional content of FLW and the impact on jobs.

4.3.1 Estimating Nutritional Content of FLW and Food Surplus

The link between nutrition and FLW or food surplus is multifaceted and not straightforward. A few studies have estimated the nutritional content of FLW; these are reviewed below. In addition, there are nutritional guidelines on food surplus being redistributed to people. These are separately discussed below.

Nutritional Content of FLW and Food Surplus

Several studies have estimated the energy content of food loss and waste. These calculations give some indication of scale of the FLW problem and helps people to visualize the amounts of food being described. These generally involve taking weight-based FLW data by food type and multiplying by the energy content for the appropriate food type.

Examples of this approach include Kummu et al. (2012) and Lipinski et al. (2013); they used data from FAO (2011) to estimate the energy in FLW by commodity type (Kummu et al. did so for North America and Oceania; Lipinski et al. did so for the whole world). These studies both involved applying factors for the average energy content taken from the FAO's food balance sheets to the different commodity groups reported by FAO. Similarly, the energy content of food loss in the retail and consumption stages in the United States has been estimated by Buzby, Wells and Hyman (2014). This involved taking the estimates in the LAFA data set and applying energy data derived from the USDA National Nutrient Database for Standard Reference.[19]

In contrast to this approach, the method described by Hall et al. (2009) in Chapter 3 undertakes the quantification of FLW in the United States using energy as the primary metric. In other words, FLW is quantified by subtracting the amount of food consumed, estimated in calories, from the food available, also estimated in calories. In this case, there is no need to convert the energy of FLW.

A recent study by Spiker et al. (2017) noted that, although energy content of FLW is important, it does not give any information on the other nutrients found within food. They argue that focusing on energy may over represent the influence of calorie-dense foods and underrepresent foods that contain high levels of micronutrients (e.g., vegetables, fruits, seafood and dairy products). They take estimated FLW data for retail and consumption phases of the supply chain in the United States from the USDA's LAFA data set and calculate the amount of 27 nutrients that go uneaten using the National Nutrient Database for Standard Reference.

A similar approach was used to quantify household FLW in the United Kingdom (Cooper et al. 2018). This used WRAP's detailed data on household food waste alongside nutritional data from the UK Composition of Foods data set (*UK Composition of Foods 7th edition)*.

There are three aspects to assessing the accuracy of these types of approaches:

- Underlying data on FLW—the accuracy of the nutritional estimate cannot exceed that of the FLW data it is based on;
- Nutritional data—given the length of time that nutritional data have been collected and refined, this will usually be more accurate than the FLW data, and therefore contribute less to any inaccuracies; and
- Matching FLW and nutritional data—to perform this type of analysis, nutritional information must be applied to FLW categories. In many cases this is straightforward, but for some food types it can be more problematic. This is an issue for FLW categories that represent foods with a diverse range of nutrients (e.g., a category of bread will likely include white bread and wholemeal bread, with differing levels of fiber and other micronutrients).

Metrics have been developed to help understand the amount of nutrients lost or wasted. Spiker et al. (2017) and Cooper et al. (2018) both compare the amount of nutrients in FLW with the recommended intake for the relevant country. Cooper et al. coined the term "nutrient days," which expressed the number of days' worth of nutrient that are contained within the average amount of household food wasted per person in a year. Previously, a study by the UK Department of Environment, Food and Rural Affairs compared the amounts of nutrients in UK household food waste with the amount of nutrients in food coming into UK homes, expressing the ratio as a percentage (Defra 2010). It would also be possible to compare the amount wasted with what is consumed, although no examples of this have been found.

The choice of comparison (e.g., comparing with recommended intake or with what gets purchased or consumed) can influence the perceived importance of the FLW of a specific nutrient. For instance, in the United Kingdom, fiber is the most wasted nutrient when compared with purchases: 22% of fiber brought into the home is wasted (Defra 2010). However, fiber is the least wasted nutrient when

[19] See https://catalog.data.gov/dataset/usda-national-nutrient-database-for-standard-reference.

compared with intake; wasted fiber represents 12% of the recommended nutrient intake. The great difference between these two results, which could lead to quite different actions being taken, is largely because of the gap between what people purchase (containing relatively low levels of fiber) and the recommended diet (with higher levels of fiber), in the United Kingdom at least. For this reason, it is recommended that nutritional assessments of FLW at the consumption phase compare the results with both purchases and recommended intake to obtain a range of useful metrics.

The estimates of the nutritional content of FLW can be useful to join up policies, interventions, and change programs related to health and FLW; for instance, creating campaigns around vegetable consumption could have a double effect of reducing waste and increasing vegetable consumption. However, as noted by Cooper et al.:

> With foods that are not associated with such positive health outcomes (e.g., sugar-rich foods), there is a potential conflict between initiatives aimed at reducing waste (e.g., a simplistic approach that asks people to clear their plates) and improving diets. In such cases, initiatives aimed at helping people to prepare and serve an appropriate amount of food become important ….

Neff, Kanter and Vandevijvere (2015) discuss at length the many interactions between health and food waste, noting where policies are complementary and situations in which they compromise one another. They conclude that policies aimed at tackling FLW should include voices advocating public health to ensure these policies areas work well together. Similar, Conrad et al. (2018) analyzed the amounts of FLW along the supply chain associated with healthy and less healthy foods. They found that healthier foods "were associated with greater amounts of food waste and greater amounts of wasted irrigation water and pesticides, but less cropland waste."

In addition to estimating the nutritional value of FLW, the Greater Vancouver Food Bank has published nutritional standards as part of their quality of food guidelines (Greater Vancouver Food Bank 2016).

Linked to this area is the estimation of the number of meals associated with a given amount of FLW. Two studies have been found that make this estimation:

- The Provision Coalition's Food Loss and Waste Toolkit uses the energy content of the food to approximate the number of meals: 700 kilocalories are assumed to constitute a single meal. Although it is recognized that the product being produced does not necessarily represent a meal (e.g., sauces or jams), it is intended to bring awareness to the calories lost (personal communication, Cher Mereweather, Provision Coalition, 2018).
- WRAP has used the weight of food to approximate the number of meals, assuming 500 grams to be a single meal.

Both organizations suggest that these approaches give a rough estimate of the number of meals. More complex methodologies would be required to ensure that the FLW in question represented something recognizable as a meal.

4.3.2 Impacts on Jobs

The relationship between jobs and FLW, food redistribution and food prevention has been the subject of a small number of studies.

One such study is the report by ReFED, which includes an estimate of 15,000 jobs created through reducing food waste by 20% in the US (ReFED, 2016, 24). These jobs are related to a range of solutions relating to food diversion, the largest two being:

- Jobs in the recycling sector (9,000 jobs): five to 10 permanent employees per facility would be required for the construction management, collection and processing of diverted food waste; a further 1,600 jobs would be required for each million tonnes of compost relating to the utilization of this material; and
- Donation storage and handling (2,000 jobs): these jobs would be in food businesses and within food recovery organizations.

The other job potential is distributed between other solutions, including centralized anaerobic digestion and donation transportation.

The ReFED report mentioned that prevention solutions were excluded because of a lack of data. Discussion with the Food Loss and Waste Measurement Expert Group convened for this project suggests that it is very difficult to make a quantitative assessment of the effect of FLW prevention on jobs and employment. However, some of the experts pointed to the many case studies where preventing FLW had increased the efficiency of a facility, thereby increasing the profitability of that facility and therefore improving the job security of those employed at that facility.[20] This rationale presented by the experts is supported by the recent studies on the business case for preventing FLW, which estimate that, for most companies, investment in prevention solutions has a short payback period (WRAP 2017c, Hanson and Mitchell 2017).

The above discussion focuses on the impact of individual businesses taking action to tackle their FLW. Only one study assessing the impact on jobs over the whole economy was found, the study by Campoy-Muñoz et al. (2017) discussed in Section 4.2. This study assessed the impact of FLW prevention on jobs in Germany, Poland and Spain using a social accounting matrix with highly disaggregated agricultural and food industry accounts data. The results suggest that FLW prevention will lead to a reduction in employment because lower amounts of food will be required by those sectors that successfully prevent FLW, with a corresponding impact on jobs within the sectors that provide this food to those sectors.

Taking these two perspectives together, this suggests that it is generally in the interests of individual businesses to prevent their own FLW. However, if this occurs widely within a country, it will lead to a reduction in the amount of food required (compared with a situation where this FLW has not been prevented). This may lead to a shock to the economy that may require management at a macro level. It is also clear that this area would benefit from more research to understand the implications in a wider range of scenarios and countries.

4.4 Summary of Estimating Impacts

This chapter has discussed a wide range of methods used to estimate the impacts associated with FLW and food surplus, as well as estimating the benefits or FLW prevention, redistribution of food surplus and treatment of FLW (rather than disposal). These impacts range from environmental (e.g., GHG emissions and biodiversity loss), financial (cost to businesses) and social (impact on nutrition and jobs). However, there is a strong interaction between these three interconnected groups, and generally a category should not be considered in isolation.

[20] E.g., those found at: https://provisioncoalition.com/Resources/FoodWaste/foodlosswastelibrary.

Many of the methods used for assessing the impact are relatively simple. They involve multiplying the amount of FLW generated (or the amount of FLW prevented, redistributed, and so on) by an impact factor that describes the intensity with which FLW affects that metric. Examples from the three categories of impact include carbon factors, which describe the GHG emissions associated with a fixed amount of FLW, the price per tonne of FLW (to estimate cost) and the nutritional content of FLW.

At the other end of the complexity spectrum, models have been developed to explore the various and complicated interactions within the food system (and between the food system and other aspects of the world). These include economic models that look at the impact of FLW prevention up and down the supply chain, as well as modeling phenomena such as the rebound effect.

The chapter has also highlighted a range of tools that exist that help organizations to estimate these impacts. Many of these are freely available; links are provided in this chapter and many of the tools are also cited in the accompanying practical guide.

5 Targets, Key Performance Indicators and Metrics

Once the baseline for FLW is quantified, an overarching target or objective can be set by an organization. Key performance indicators (KPIs) are then used to determine the success of the organization in achieving that objective or evaluating specific activities. The use of a well-chosen suite of metrics is important for organizations wanting to bring about positive change—for example, FLW prevention, redistribution or diversion initiatives. It is worth noting that the terms target, KPI, and metric are often used interchangeably. A target is the goal or overarching objective. A KPI is defined as a quantifiable measure used to evaluate performance against that target and a metric is defined as a set of criteria that measure results.

There are a number of metrics to consider, which fall into four broad categories:

- **Weight-based metrics:** the amount of food going to a destination, redistributed to people or prevented, expressed as weight and quantified using methods described in Chapter 3.
- **Impact metrics:** expressing the amount of FLW, food redistributed or waste prevented using metrics that describe the impact (e.g., environmental, social, financial) via methods described in Chapter 4.
- **Facilitating metrics:** tracking changes that are necessary to bring about a desired change. Examples include the proportion of staff trained to prevent FLW, or frequency of line failures.
- **Indirect metrics:** Measurement of indirect impacts of prevention, redistribution or diversion activities (e.g., in primary production, the amount of a commodity produced or sold per unit input—e.g., fertilizer, acre of land—which should increase as FLW is decreased, all other things being equal).

Organizations monitoring progress toward their chosen goal can manage this process (and communicate success) more effectively if they have a range of appropriate metrics; consideration should be given to metrics from all four categories.

This chapter discusses these four types of metric and provides examples of their use in North America and beyond. In addition to these categories, the chapter also discusses important issues to consider when choosing key performance metrics, including those relating scope (what to include), frequency of measurement and normalization.

5.1 Weight-based Metrics

Weight-based metrics track the amount of FLW or food surplus being generated, the amount going to specific destinations or redistributed, or the amount of FLW being prevented. They are arguably the single most important type of metric (assuming the metric has the right scope and is measured accurately), as they directly measure the change being targeted. They usually form the basis for estimating impact metrics (Section 5.2), so are necessary to derive these.

The scope of a weight-based metric is crucial to its appropriateness. As discussed extensively in Chapter 2 and elsewhere, KPIs should be designed to align with the desired outcomes of an organization. Taking a simplistic example, if a manufacturer is targeting source reduction of FLW to increase its conversion of ingredients to a saleable product, then a weight-based target should be tracked. That target should include the amount of FLW generated to all relevant destinations and also includes food surplus redistributed for animal feed and human consumption.

Weight-based metrics can be tracked at a range of scales. In a business, these could be tracked at a corporate level (i.e., for the whole business), at the facility level (e.g., for an individual factory) or for individual processes (e.g., a particular production line, or even one stage within that line). The decision about which levels to monitor will depend on what a business is trying to achieve:

- **Identifying problems and estimating return:** requires approximate estimates of amount of FLW for different types of facility and processes within facilities. This requirement may not necessitate long-term monitoring.
- **Monitoring implementation:** if a change is made, for example, a technical change is made to a process or to training to change how people interact with a process, focused monitoring may be required to assess the effectiveness of the change. This may require frequent monitoring (e.g., daily, weekly) of the process(es) affected over a relatively short period of time (long enough to assess whether the desired change has occurred and whether it is stable).
- **Corporate reporting and communication:** this requires collation of information for a whole business, usually quarterly or annually, that allows the company to understand its overall progress toward its targets, report these to other organizations (e.g., if part of a wider agreement) and, potentially, communicate them publicly.

Most of the examples of weight-based metrics in the public domain come from this latter category of corporate targets that apply to a whole organization. In addition, there are several case studies relating to specific changes in a facility; while these are not specifically KPIs (as they do not represent ongoing monitoring with targets), they show the results of monitoring in relation to change management.

5.1.1 Primary Production

KPIs relating solely to primary production are limited. This is partly because in-field and pre-harvest losses can be difficult to quantify; for instance, food spilled during harvest is by definition not collected and therefore not possible to weigh, although the amount can be estimated by comparing average crop yield per hectare and amount harvested per hectare. It is also rarely a producer's priority to develop this metric, with more emphasis instead placed on total crop harvested, an example of an indirect metric (Section 5.4). Where post-harvest KPIs exist for primary production, they mostly form a subsection of a wider FLW target.

No weight-based targets specific to North America were found in the public domain for primary production. However, Sustainable Development Goal 12.3 includes the aim to "reduce food losses along production and supply chains, including post-harvest losses," and the methods for quantifying this have been proposed in the food loss index methodology. This is an unquantified indicator (i.e., there is no target for the scale of reduction); however, it does provide a directional goal.

The United Kingdom–based retailer Tesco does publish data on FLW at each stage of its supply chain. This includes a calculation of the in-field losses of five priority products (apples, bagged salad, bakery, bananas and grapes) (Tesco 2014). This information helps to inform Tesco's broader KPI to halve food waste in their supply chains by 2030 (Tesco 2018a).

5.1.2 Processing and Manufacturing

Food processors and manufacturers have pledged to track a range of metrics relating to FLW. In the United States, these metrics often conform to the Food Loss and Waste 2030 Champion pledge, which is a public commitment to reduce food waste and loss by 50% by 2030. There are currently 21 signatories (known as the 2030 Champions), including Campbell's Soup Company and ConAgra Foods. Within this commitment, these companies have also set KPIs more specific to their own operations, including:

- Campbell's Soup Company: Reduce landfill of food waste from manufacturing operations by 50% by 2025 (Lillard 2017). Methods to achieve this include reconfiguring production equipment to decrease ingredient waste during processing (food waste prevention), and diversion to animal feed (reuse) (Campbell Soup Company 2018).
- ConAgra Foods: Reduce waste generated in facilities by one billion pounds by 2020, including preventing food waste in production and diversion to animal feed (ConAgra Foods 2016).

A similar target has been set by the Canadian company Maple Leaf Foods, which has committed to reducing waste to landfill in manufacturing facilities by 50% by 2025 (2015 baseline year). Current efforts focus on the diversion of waste food to biodigesters for energy recovery and fertilizer production (Maple Leaf 2017), as well as food waste prevention assessments within selected manufacturing plants. Meanwhile, the US retailer and producer Publix has made a commitment to divert by-products from its dairy and bakery manufacturing plants to animal feed (unquantified target in publicly available data) (Publix 2018). In addition to reducing food loss and waste by 50% overall, the food manufacturer, Kellogg, also aims to reduce total waste in its manufacturing plants "by 15% per metric tonne of food produced" by 2020 (Kellogg 2017).

As is clear from the above examples, diversion from landfill is the main KPI of the examples found for the processing and manufacturing stage. Exceptions to this do exist, including several North American manufacturers who have engaged with the Canada-based Provision Coalition's Food Loss and Waste Toolkit (based on Enviro-Stewards' prevention-based approach) and the KPI Dashboard.[21] Among other actions, the FLW toolkit helps businesses to identify inefficiencies in production that contribute to food loss and waste (Provision Coalition 2018c). Manufacturers using the toolkit can quantify FLW by weight, cost (of all resources wasted; not simply disposal cost), electricity and water use, embedded and added GHG emissions and calorific value. These values can then be monitored and tracked over time in the KPI Dashboard (Provision Coalition 2018). Manufacturers using the toolkit can quantify FLW not only by weight, but also cost (of all resources wasted; not simply disposal cost), electricity and water use and calorific value (see Section 5.2).

Several case studies using this tool exist, including one from Fruition Fruit and Fills, a manufacturing plant owned by Tim Hortons Inc. The case study was developed by Enviro-Stewards. Fruition Fruit and Fills piloted efficiency initiatives at its production plant, which successfully reduced food waste by 80% and GHG emissions by 30%, as well as giving a 260% financial return on investment (Clean 50 2014). Similar metrics were used to quantify FLW prevention at other manufacturers, including Campbell Soup Company (2018), Byblos Bakery (2017), Calgary Italian Bakery Ltd. (2017) and Hans Dairy (2018) (Provision Coalition 2018a). Hans Dairy was able to quantify its potential savings in raw milk loss (by liter); financial savings, including embedded environmental reductions, energy, water and GHG reductions; and an equivalent number of meals based on calorific content (Provision Coalition 2018b). Although these metrics have not formed a publicly-facing target like many of the other KPIs, these metrics are applicable to other industries and could be used in this way (Network for Business Sustainability 2014).

[21] See https://sms.provisioncoalition.com/tools/kpidashboard.

5.1.3 Wholesale and Distribution

Distribution is rarely considered in isolation, because of relatively low levels of FLW in many countries and the fact that distribution is often managed by another stage of the supply chain (e.g., retail). Where it is explicitly named, FLW metrics tend to focus on reducing waste going to disposal (Nestlé 2015, Target 2016). Other potential metrics might include product damage or spoilage. Research by the Mexican Transport Institute (*Instituto Mexicano del Transporte*) tracked pineapple damage and spoilage associated with different distribution methods (cold storage vs. ambient) (CEC 2017b). Reducing the weight or volume of damaged and spoiled product could be used in such cases as a KPI.

Although often considered as part of other stages, the distribution stage of the supply chain may be of higher importance in some countries. For instance, in hotter countries (e.g., Mexico) and large countries with low population densities (e.g., Canada), there is a higher potential for spoilage during distribution compared with more temperate or densely populated countries. Therefore, in countries where it is contributing to total FLW substantially, it is useful to have metrics that separate distribution from other supply chain stages.

5.1.4 Retail

Metrics at the retail stage are more diverse, although diversion from disposal and landfill remains a major feature.

Costco Wholesale, which owns stores across North America, measures food waste by tonnage, and diverts away from disposal by donating edible food, repurposing as fertilizer, diversion to animal feed and energy recovery (Costco 2017). There are no publicly available data on the total weight of food waste produced by Costco, and its food donations and diversion from landfill are reported as separate metrics.

Kroger, a US-based retailer, also employs the principles of the FLW hierarchy multiple stage to reach its target of zero waste to landfill by 2020, defined as meeting and exceeding “EPA’s Zero Waste threshold of 90% diversion from landfill in our facilities by 2020” (Kroger 2018). Subsets of Kroger’s goal include a social goal of donating three billion meals by 2025 and achieving zero food waste in all stores “and across Kroger” by 2025 (Kroger 2017). The definition of “zero waste” in relation to this target is uncertain.

The Dutch-owned parent company Ahold Delhaize (brands include Hannaford and Food Lion in the United States, among others) has several KPIs around food waste. As a member of the Consumer Goods Forum, Ahold Delhaize has a target of diverting 50% of food waste away from disposal by 2020 (2016 baseline). It is worth noting that Ahold Delhaize normalizes its food waste data, measuring food waste tonnage against food sales (reported as tonnes per million euros [t/MEUR]) using constant exchange rates. These normalized data are used to inform its second food waste KPI of reducing total food waste by 20% by 2020 across its supply chain. Methods include in-store preventive measures to reduce food waste, as well as donation and recycling. As a final, separate target, the company also aims to recycle 90% of food waste across its brands by 2020 (2016 baseline) (Ahold Delhaize 2017).

The United Kingdom–based retailer Tesco achieved its 100% diversion from landfill goal in 2009. Its more recent KPIs include eliminating “all edible food waste in … stores and distribution centres” (Tesco 2018b).

5.1.5 Food Service, Hospitality and Institutions

Broadly, the food service, hospitality and institutional catering industries have either adopted KPIs centered on diversion from disposal or on achieving an absolute reduction in food waste produced.

Waste to landfill targets range from 25% to 100% diversion rates, and generally include inedible parts in the overall metric (Hilton 2018, McDonalds 2017, Darden Restaurants 2018). Which areas of operations are targeted can vary; for example, McDonalds's target is to recycle 50% of in-restaurant waste by 2020 (McDonalds 2017), while Darden Harvest's zero waste to landfill target includes both kitchen and restaurant waste (Darden Restaurants 2018). Yum, the parent company of Pizza Hut, Taco Bell and KFC, has set a goal of diverting 50% of back-of-house operational waste generated by its restaurants in the United States by the end of 2020 (Canada is not mentioned). This is part of Yum's status as a US Food Loss and Waste 2030 Champion (Yum 2015).

Other industries have adopted a combination of KPIs. Aramark, a leading food service provider for schools, hospitals, sports and entertainment venues, businesses and governments, has adopted different strategies for front- and back-of-house operations. Aramark's overall target is to reduce food waste by 50% by 2030 (Aramark 2017). Further metrics used to measure progress include weighing back-of-house food waste to monitor prevention strategies (reported as percentages, normalized against number of outlet sites); tonnes diverted from landfill; and kilograms of food donated. In its front-of-house operations, Aramark measures food waste reduction by weight, normalized against the number of consumers, with a reported food waste prevention result of 57 grams (two ounces) per person through front-of-house interventions (Aramark 2017).

More organizations seem to focus on food waste prevention (the top of the FLW hierarchy) in the food service and hospitality industry than at other supply chain stages. Compass Group North America, a major food service company, has adopted a target to reduce food waste generation by 25% by 2020 (2016 baseline). Compass Group defines food waste as "discarded food that is safe for human consumption" and aims to reach its target through source reduction and food waste prevention at the consumer, supplier and back-of-house stages (Compass Group 2017).

Similarly, the retailer IKEA has a goal to reduce food waste in its restaurants and smaller bistros by 50% by 2020 under its Food Is Precious Initiative. Food waste is measured by "smart scales" in IKEA kitchens and efficiencies implemented to reach the target. Progress so far has been reported in terms of the number of stores involved in the initiative, reduction in food waste by weight, reduction in CO_2 emissions, and staff satisfaction with the program ("% of food co-workers [who] are proud of the initiative and … are taking measures also at home to decrease food waste") (IKEA 2017).

Starbucks has adopted a social KPI of rescuing "100% of food available to donate" from all US company-owned stores by 2020, with the aim of donating 50 million meals per year (Starbucks 2017).

5.1.6 Households/Residential

Food waste by weight or volume is often used as an indicator at the household level, normalized per capita. This is the KPI associated with SDG 12.3 ("By 2030, halve per capita global food waste at the retail and consumer levels"), and it therefore informs Champions 12.3 members' targets. Nestlé's commitment to Champions 12.3 extends to reducing food waste at a household level, with actions including the development of a food use app which helps consumers to keep track of and use the food that they buy (Nestlé 2017). There are apparently no publicly available data on how Nestlé quantifies its influence on household consumption.

Love Food Hate Waste Metro Vancouver quantifies household food waste (defined as all food, edible and inedible, that was disposed of) by tonnage. The KPI attached to Metro Vancouver's Love Food

Hate Waste campaign is to reduce household food waste by 10% per capita by 2020 (2014 baseline) (Love Food Hate Waste Metro Vancouver, no date). This is in addition to waste diversion targets.

The "Food Too Good to Waste Challenge" in the United States encourages households to track their preventable food waste by volume and weight and compare these metrics at the beginning and end of a six-week food waste prevention challenge (EPA 2016a). This is in addition to food diversion targets. Similarly, the province of British Columbia, Canada, has a household food waste prevention target of 30% and aims to divert 90% of organic waste from landfill by 2021 (Province of British Columbia 2016).

5.1.7 Indicators Covering Multiple Supply Chain Stages

The US national goal, announced in 2015 by the EPA and USDA, is to reduce food waste by 50%. The effort has two different baselines using data from each agency, with the goal of seeing a 50% reduction in both baseline measurements. The EPA measurement covers food going to landfill and incineration from "residences, commercial establishments (e.g. grocery stores and restaurants), and institutional sources (e.g., school cafeterias)" (EPA 2017). As it only covers disposal, the EPA part of the national goal can be seen as focused on diversion. The USDA measurement estimates the amount of available food in the United States that went uneaten at the retail and consumer levels. This implicitly covers a much wider range of destinations; tracking this uneaten food should provide information to use in prevention of food loss. Currently, neither Mexico nor Canada has an equivalent target that has been publicly stated.

Not all governmental organizations with FLW strategies include indicators. A review of governmental plans (mostly from the United States) to address food waste found that only one-third of plans include an evaluation component, and of these, 25% did not include a specific target (Gorski et al. 2017). The plans covered various points of the supply chain, and the parameters of the study defined food waste as "food that could have been edible but was landfilled or incinerated" (Gorski et al. 2017).

Champions 12.3 members and US Food Loss and Waste Champions 2030 have all committed to reducing food loss and waste by 50% by 2030. This commitment can apply to the whole of the supply chain or to individual stages, according to the member organizations' involvement with different stages. In total, there are 21 organizations signed up as 2030 Champions, and almost 40 executives registered as Champions 12.3, representing governments, businesses and organizations across North America and the globe (Champions 12.3 2018). The Food Waste Reduction Alliance (a collaboration of the Grocery Manufacturers Association, the Food Marketing Institute and the National Restaurant Association in the United States) also aims to reduce food waste across the supply chain by 2030. The alliance is working with 30 organizations in the US government and private sector to achieve this goal (Food Waste Reduction Alliance 2013).

The Consumer Goods Forum has adopted a similar KPI to halve food waste (defined as edible and inedible food parts sent to disposal) across retail and manufacturing by 2025 (Consumer Goods Forum 2018).

Nestlé and PepsiCo Foods Canada have both committed to zero waste for disposal (including food and organic waste) in their factories and distribution centers (Nestlé 2017) (PepsiCo Canada 2017). Administrative authorities at the state and municipal levels have also adopted diversion from landfill as a metric. Newfoundland and Labrador (Canada) have a diversion target of 50% for organics from businesses, retailers and households (no specific food waste target); Ontario (Canada) has a target of 40% organics diversion by 2025, increasing to 60% by 2035; a 50% to 70% food waste reduction and diversion target for municipalities, industries, institutions and households is under consultation

(Ontario.ca 2018). In the United States, the Minnesota Pollution Control Agency aims to increase its organics waste collection by 15% (food waste included within this) (Minnesota PCA 2016).

5.1.8 Weight-Based Metrics: Summary

This section has demonstrated that there are many relatively diverse metrics in the public domain related to FLW. Examples were found across the supply chain, although few examples were found in primary production and distribution. A greater number of targets covered diversion from landfill (and other disposal destinations) compared with FLW prevention. From the documentation reviewed, it was not always possible to assess what was covered in a given metric—whether it included inedible parts or not and exactly which destinations were included in the quantity being tracked.

5.2 Impact Metrics

In addition to weight-based metrics, many organizations also track the associated financial, environmental and social impacts of the changes they are making. Some of these organizations have publicly stated targets and others have published case-studies that have quantified the positive impact achieved relating to FLW prevention, redistribution or diversion from disposal. The methods for calculating these impacts are discussed in detail in Chapter 4.

Many of the issues relating to weight-based metric also apply to impact metrics. As discussed in Section 5.1, it is important to align the scope of the metric (e.g., which destinations to include) with organizational objectives. Generally, impact metrics are used for two purposes:

- Prioritization to identify and tackle the area of FLW with the largest financial, environmental, or social impact; and
- Communication of positive change or the size of the issue—converting FLW into other "currencies" can increase the impact of these statistics.

These are used much less frequently for the direct management of change relating to FLW. Possibly because of this, there are many fewer examples of impact targets in the public domain compared with weight-based metrics.

Primary Production

No impact metrics were found in the public domain for this supply chain stage.

Wholesale and Distribution

No impact metrics were found in the public domain for this supply chain stage.

Processing and Manufacturing

The Provision Coalition's Food Loss and Waste Toolkit allows manufacturers to convert the FLW produced into a range of other metrics: cost (of all resources wasted; not simply disposal cost), electricity and water use and calorific value. The latter is also expressed by number of meals. This toolkit allows companies to set and monitor appropriate FLW targets, either weight-based or relating to impact.

Retail

No impact metrics were found in the public domain solely for this supply chain stage. Walmart's Project Gigaton is discussed below.

Food Service, Hospitality and Institutions

As mentioned in the previous section, IKEA reports progress against its food-waste prevention target by GHG emissions (as well as weight of FLW) (IKEA 2017).

Household

No impact metrics were found in the public domain for this supply chain stage.

Food Rescue

Anti-hunger organizations such as Food Rescue (Canada) and Feeding America (United States) have KPIs linked to amount of edible food saved from going to waste, which are expressed as a weight and the number of meals served per day or per year. Food Rescue's stated KPIs include serving 30,000 meals per day, while Feeding America reported rescuing 3.3 billion pounds of food from farms, manufacturers and consumer-facing businesses in 2017 (Food Rescue 2018) (Feeding America 2018). Food Rescue also calculates the GHG emissions averted as part of its food recovery program (Food Rescue 2018).

Indicators Covering Multiple Supply Chain Stages

Spanning the entire supply chain, and operating across many countries, Walmart's Project Gigaton is a prominent example of an environmental-impact target. Project Gigaton aims to prevent one billion metric tonnes of carbon dioxide emissions from its global value chains by 2030. Reducing food loss and waste is a subset of actions that feeds into this target, and Walmart encourages organizations in every stage of the supply chain to contribute to this target (Walmart 2017).

The Department of Environmental Quality, Oregon (United States) defines its food waste reduction targets according to broader environmental impact. Its aim is to address GHG emissions, water use, energy use and wasted resources by reducing the generation of wasted uneaten food by 15% by 2025 and 40% by 2050 (Department of Environmental Quality 2012).

Provision Coalition's KPI dashboard was designed to improve efficiency and reduce food waste through monitoring and tracking of the waste generated, the cost of waste per unit of production, and waste reduction goals within processing and manufacturing. The dashboard suggests three indicators that specifically target food loss and waste (KPIs may be applicable at various supply chain stages). These are waste production (separated into food waste sent to aerobic digestion, animal feed, compost, controlled combustion, donation, land application, landfill, organic, recycling and waste to energy); wastewater production and waste diversion (Provision Coalition 2018c). These indicators, particularly prevention and diversion from disposal, are the most commonly used throughout the supply chain. Further possible indicators include environmental or social metrics.

One innovative method used to combine a range of data on FLW destinations for communication purposes comes from the Flemish Food Supply Chain Platform for Food Loss (2017) in Belgium. In this publication, a "cascade" index was created, giving a score to each destination in terms of its position on the food recovery hierarchy (e.g., food redistributed to animal feed is a score of 10, food going to landfill is a score of zero). These scores are applied to the amount of material going to each destination from each supply chain sector (and, in some cases, subsectors), creating a score for each. These scores can be compared between sectors and could, with ongoing monitoring, be tracked over time.

5.3 Facilitating Metrics

Facilitating metrics do not quantify FLW or food surplus. Instead, these track information that reflects whether facilitating conditions exist to achieve targets relating to FLW or food surplus. Generally, these are likely to be used internally by organizations and are therefore unlikely to contribute to public-facing targets. Discussions with members of the Food Loss and Waste Measurement Expert Group suggest that many businesses are using this type of metric. Nevertheless, two examples were found in the public domain.

As part of IKEA's work to reduce food waste in its restaurants and smaller bistros by 50% by 2020, the company monitors staff satisfaction with the program. The metric used is: '% of food co-workers [who] are proud of the initiative and … are taking measures also at home to decrease food waste') (IKEA 2017). This presumably reflects the importance that IKEA places on the human component of change—it will not happen unless staff engages positively with the program of work, to the extent that it is a public-facing KPI.

Another example found was for the Canadian farming cooperative, RedHat, which grows all its produce in greenhouses, meaning that it must be picked. This enabled RedHat to quantify the percentage of produce that was classed as second grade and therefore destined for disposal. The metric ultimately supported a resale program that helped reduce food waste; the amount and destination of lower-grade produce could therefore be used as a KPI in some cases (CEC 2017b). By monitoring one of the precursors of waste (the proportion of food grown at different grades) this allows RedHat to manage change more effectively.

5.4 Indirect Metrics

Achieving goals relating to FLW (e.g., source prevention) will often have positive impacts in several ways for a business or other organization. An example of such a KPI is the amount of natural resource input (e.g., land) per unit of food produced. If the business reduces FLW and becomes more efficient, then the amount of input (land) required for a given output will decrease (all other things being equal). By tracking these indirect metrics, alongside KPIs from the categories previously discussed, these indirect impacts can be assessed, and relationships between them and FLW can be understood.

No examples of this category of metrics were found in use in the public domain explicitly linked to FLW.

5.5 Other Considerations Relating to Metrics

5.5.1 Normalization

Normalization of a metric involves reporting a quantity (e.g., of FLW) relative to another, relevant quantity (e.g. amount of food processed in a facility). Generally, normalization leads to more appropriate comparisons over time, for example, by removing the effect of companies changing in size over the relatively long timescales involved in their targets.

Most targets reviewed for this section appear to be unnormalized. However, a few examples were found.

In the retail sector, Ahold Delhaize normalizes its weight of FLW against food sales (using constant exchange rates), reporting the normalized quantity in units of tonnes per million euros (t/MEUR) (Ahold Delhaize 2017).

In catering/food service, Aramark measures FLW reduction in its front-of-house operations by weight and normalizes this data by number of customers (e.g., Aramark has reported a decrease in FLW by two ounces per person [Aramark 2017]).

For household FLW amounts, normalization is often per capita. For example, KPI attached to Metro Vancouver's Love Food Hate Waste campaign is to reduce household food waste by 10% per capita by 2020 (Love Food Hate Waste Metro Vancouver). Data for households can also be expressed per household (e.g., WRAP 2017b).

The US EPA's goal to halve FLW by 50% by 2030 is being tracked by weight of FLW per person going to landfill and combustion facilities.

5.5.2 Frequency of Measurement and Reporting

Deciding on how often to repeat measurements for KPI tracking is an important step to managing FLW. As discussed in Section 5.1, this is closely linked to the purpose of the tracking FLW.

Where measurement is to understand the impact of a specific change (e.g., to a specific process in a facility), then it is often necessary to take multiple measurements before the change. In addition, sufficient measurements are required during and afterward to quantify the magnitude of change and assess whether it is stable. The gap between measurements could be relatively short (hours, days or weeks).

In contrast, metrics used for corporate reporting and communication are often reported quarterly or annually and therefore measurements are unlikely to require the same time resolution as those for assessing a specific change.

5.6 Summary of Targets, Key Performance Indicators and Metrics

This chapter has explored targets, key performance indicators and metrics that are used to measure and manage issues relating to FLW. The findings should be qualified by the fact that they reflect what is in the public domain; other metrics are likely to be used by organizations that are not designed to be public facing.

A range of metrics have been found, spanning all sectors of the supply chain. These have been adopted by businesses, NGOs and governments. A majority of these metrics are weight-based: measuring the amount of FLW going to specific destinations, food redistribution or FLW prevention. Those metrics in the public domain are relatively diverse. Examples were found across the supply chain, although few examples were found in primary production and distribution.

Many of the examples in North America focus on diverting food away from landfill. This may be to a specified destination (e.g., to feed hungry people, to anaerobic digestion) or simply tracking the reduction in wasted food sent to landfill. This is despite the larger financial savings and positive environmental impact usually being derived from source reduction (i.e., preventing food from being wasted in the first place). However, of the metrics found, a minority did focus on food-waste prevention.

From the documentation reviewed, it was not always possible to assess what was covered in a given metric, particularly whether it included inedible parts or not and exactly which destinations were included in the quantity being tracked. This makes it difficult to assess the exact balance between diversion and prevention in KPIs published by businesses.

A relatively small number of impact metrics were also found. These included targets relating to GHG emissions and other environmental indicators. In addition, many food rescue charities quantified their results by the number of meals served.

A small number of metrics related to the facilitating conditions required to tackle FLW. Two examples were found in the public domain, although discussions indicate that more unpublished examples of this type of indicator are likely to be used by many businesses.

Many metrics appear to be unnormalized (e.g., they simply state a reduction in the quantity of food being lost, wasted, or sent to landfill). There is a small number of examples of metrics being normalized by appropriate factors (e.g., by turnover, number of customers). Generally, normalization leads to more appropriate comparisons over time by removing the effect of companies changing in size over the relatively long timescales involved in their targets. However, it requires the normalization factor to be appropriate; the closer it can be to the amount of food being processed, sold or similar, the stronger it is.

The review presented in this chapter suggests there is merit in developing guidance on how to develop, monitor and publish key performance indicators and metrics in general. This will allow the pockets of good practice that have been found to be adopted more widely, allowing swifter action to tackle FLW.

6 Key Conclusions and Recommendations

This report has collated information from a diverse range of sources to examine the state of affairs relating to quantification of food loss and waste (FLW) and surplus in Canada, Mexico and the United States. In addition, it has reviewed the methods used for estimating the impact of FLW and the key performance indicators that have been adopted.

Chapter 2 demonstrates that there is a range of definitions and terms used to describe food loss, waste and surplus. Multiple terms are used to describe the same flow of food, and some terms are used in several different ways. A degree of standardization would be helpful in this regard, while maintaining flexibility as different organizations want to focus, justifiably, on different aspects of the issue. This will take the increasing number of organizations who are providing leadership in this field to be brought together to resolve some of the more prominent differences in terminology. In the absence of such standardization, the key recommendation is that organizations be explicit and clear about the definitions and terms that they are using.

Chapter 2 also discusses the wide range of reasons why FLW is quantified. Key recommendations emanating from this are that all organizations involved in quantifying FLW should have a clear understanding of what they want to achieve from quantification and ensure there is a clear link between the quantification approach that they have adopted and these objectives.

Chapter 3 highlights the wide range of quantification methods available to organizations. For most of these, the strengths and weaknesses of these methods are reasonably well understood in a range of situations. However, this does not necessarily make the choice of method universally easy; in many situations, a quantification approach that is sufficiently accurate for an organization's purposes is too expensive. Conversely, affordable methods may not have sufficient accuracy. There should be careful consideration of the different compromises and trade-offs. This is easier if the organization in question is clear about what it would like to achieve from quantifying FLW and how this information will be used. In many situations, it is possible to achieve FLW-related aims with rough estimates or even qualitative information (i.e., without quantification at all).

Previous studies have highlighted a difference in the choice of quantification methods between governments and businesses. These reflect differences between these two types of organization:

- Businesses have focused on their own part of the supply chain, although there are some examples of companies also considering their suppliers and customers. As a result, most of the focus on quantifying household FLW has been by governments and NGOs.
- Businesses and governments also differ in their access to the FLW studies: businesses usually have direct access to their own FLW, whereas governments (and NGOs and academics) that want to quantify FLW from businesses rely either on secondary data or on obtaining permission to access these FLW flows.
- The objectives of these two groups differ: businesses often focus on quantification to inform the business case, followed by ongoing monitoring to ensure they achieve the intended savings. Governments often quantify FLW to understand which sectors are national (or state or provincial) priorities, to develop policy and to track changes for national and international targets.

For estimating the financial, environmental or social impacts of FLW (Chapter 4), most methods rely on factors that convert the weight of FLW to these other impacts. For environmental impacts, there are well-developed frameworks (mostly based on life-cycle analysis) that underpin calculations for GHG emissions, water footprints and land use. This means that factors and calculation tools already exist and that they can give reasonable estimates of a range of environmental indicators. Although methods to estimate the impact of FLW on biodiversity, energy use and fertilizer use do exist, these are emerging and are still being refined. Similarly, for some social impacts (e.g., the nutritional content of FLW), methods have been recently developed and will likely be further refined in future years.

For calculating the financial impacts of FLW and food surplus, there is a wide spectrum of complexity of methods. At the simpler end of the spectrum, calculations involve multiplying the weight of food waste by the cost per unit weight. The factors used can take into account a range of costs—for example, waste management costs, cost of the ingredients and/or embedded costs added in that supply chain stage. The choice of the factor should reflect the reason for estimating the financial impact. If the financial impact of FLW prevention is being assessed, it is important to include all the costs that could be saved if the food is not wasted. Using only waste management costs can greatly underestimate the total cost to a company of wasting food, with a deleterious effect on decision making.

More complex analyses consider how an economy may adjust in response to changes to FLW. Existing studies analyze the rebound effect and interactions between food sectors in the economy. There are currently few studies of this type and the estimates they contain are likely to be approximate. Nevertheless, they could help to inform policy makers of some of the indirect consequences of tackling FLW, including impacts on spending, GDP and jobs.

In estimating these impacts associated with FLW, it is important for studies to describe what is being quantified. Usually this is the gap between the current situation and a counterfactual (i.e. a hypothetical situation used for comparison purposes). It is recommended that the counterfactual is appropriate for the analysis in question and explicitly described.

A range of metrics and key performance indicators have been found spanning all sectors of the supply chain (Chapter 5). These metrics fall into four categories:

- **Weight-based metrics,** which quantify the amount of FLW, food surplus, and so on;
- **Impact metrics,** which estimate the impact;
- **Facilitating metrics,** which track changes necessary to bring about a desired change (e.g., the proportion of staff trained to prevent FLW, or frequency of line failures); and
- **Indirect metrics:** Measurement of indirect impacts, for example, in primary production, the amount of a commodity produced/sold per unit input (e.g. fertilizer, acre of land), which should increase as FLW is decreased, all other things being equal.

There are many examples of weight-based metrics being adopted by businesses, NGOs and governments in North America. A majority of these focus on diverting FLW away from landfill, with a smaller number focusing on preventing food waste at source. There are a small number of impact and facilitating metrics in the public domain; no examples of indirect metrics being explicitly linked to FLW were found.

A minority of business KPIs have published details of how they would be monitored and the exact scope of the metric. In addition, only a small number of metrics appear to be normalized; if normalization is done effectively, it leads to more appropriate comparisons over time by removing the effect of companies changing in size. The review of KPIs suggests there is merit in publishing guidance on how to develop, monitor and publish key performance indicators.

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