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Food waste accounting

*Methodologies,
challenges and
opportunities*

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Abstract

Food waste (FW) reduction is a priority both at global and European level. In the context of the Sustainable Development Goals defined by the United Nations, there is a specific target (12.3) referring to food waste, and asking - 'By 2030, to halve per capita global FW at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses'. The European Commission has committed to achieve this goal and defined FW as a priority within the Circular Economy Action Plan. Moreover, in order to achieve the circular economy objectives, to support the achievement of the SDG 12.3 target and maximise the contribution of all actors, the Commission established the EU Platform on Food Losses and Food Waste. This platform aims at supporting a wide array of actors in defining measures needed to prevent food waste, sharing best practice, and evaluating progress made over time.

A crucial aspect to achieve FW reduction targets is to have a robust account of FW generated along the food supply chain. The accounting, in principle, should allow: i) the identification of the most important FW streams, ii) the definition of a baseline to monitor FW reduction over time, and iii) the recognition of FW flows that may undergo a valorisation process in a circular economy perspective. Although studies can be found in the literature that estimate FW at the EU level, results are dissimilar because of different accounting approaches followed. At present, a consolidated framework for FW quantification in Europe is still an open challenge.

To contribute to the development of harmonized and robust FW accounting methodologies and FW quantification, the Joint Research Centre of the European Commission, organized a technical workshop entitled 'Food waste accounting: methodologies, challenges and opportunities'. The aim of the workshop was to gather experts in FW accounting to share experiences and perspectives on FW quantification at the European scale. Opportunities and challenges to improve FW quantification have been discussed in order to ensure that future policy decisions for FW reduction and valorisation are made based on robust information. This report summarizes the issues discussed in the workshop as well as research gaps and challenges existing in FW accounting.

Several research gaps were identified during workshop. The most critical were related to the lack of a clear and consensual FW definition and a harmonized methodology for FW accounting. The harmonized methodology requires at least clarifying: definitions and terminology (e.g. edible/inedible and avoidable/unavoidable food waste), system boundaries, and units of measurement so that existing data across countries, commodities, and FSCs could be comparable. It was also identified the need to improve overall data quality and quantification of specific waste streams, such as liquid waste. Moreover, research is necessary to identify systematically types and sources of uncertainty and variability within the FW accounting framework and provide guidelines and tools to assess them. Additionally to the mentioned methodologic aspects, other needs exist to support the better design of policies for FW reduction. Those include matching methodological aspects and policy questions, as the information required is different depending on the area of policy intervention (either waste prevention, management or valorisation). Moreover, the identification of FW drivers is of extreme relevance for both designing properly the framework for primary data collection and defining effective reduction strategies.

1 Introduction

Around 88 million tonnes of food are wasted annually in the EU along the food supply chain (FSC), from primary production up to consumption, with associated costs estimated at 143 billion euros (FUSIONS, 2016a). This figure reflects the high level of inefficiency of the FSC that has significant economic, social and environmental impacts. Besides being associated to significant economic losses, food waste (FW)¹ exacerbates food insecurity and malnutrition, and, increases pressures on climate, water, and land resources contributing to natural resources depletion and environmental pollution (Godfray et al., 2010).

In this context, the European Commission (EC) has identified FW as one of the priority areas of the European Circular Economy Action Plan. This plan presents a set of actions to be implemented in Europe to facilitate and promote the transition to a more circular economy, 'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised' (European Commission, 2015b). Besides, the EC has also committed to achieve the United Nations (UN) Sustainable Development Goal (SDG) 12.3 target of 'By 2030, halve per capita global FW at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses' (UN, 2017) (European Commission, 2015b). Indicators to monitor SGD 12.3 target are under development. FAO has presented the 'Food Loss Index' to be used as indicator to monitor food losses along the supply chain for all utilizations (food, feed, seed, industrial, other), up to the retail/consumption level (target 12.3.1). An indicator to monitor food waste occurring at the retail and consumption stage (target 12.3.2) has yet to be developed (Champions 12.3, 2017; FAO, 2017).

The EC is proposing an amend to the Waste Framework Directive (WFD) setting as obligatory the monitoring and the reporting on FW by Member States (MS) to establish a baseline for monitoring the achievement of FW reduction targets and help in the identification of relevant FW streams to be valorised in a circular economy perspective (European Commission, 2015a). FW represents high potential to support the transition the bioeconomy that 'encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy' (European Commission, 2012). The share of FW that is not reduced can be valorised by being transformed in biomaterials or bioenergy. The application of bioeconomy principles such as the cascade use of materials applied to FW can contribute the optimization to the bio-economy and simultaneously close the loop of the food system, reducing environmental burdens and boosting social development.

The development and ongoing implementation of the above mentioned policies – the Circular Economy Action Plan (European Commission, 2015b) and the legislative proposal amending WFD (European Commission, 2015a) – are a reflex of the high commitment of the EC to address the FW problem and implement strategies for its reduction. At the operational level, the EC established the EU Platform on Food Losses and Food Waste (FLW), a public-private initiative coordinated by DG SANTE. It was created to respond to the call of the Communication on Circular Economy on the Commission to establish a Platform dedicated to FW prevention (European Commission, 2015b) and it aims to support all actors in: defining measures needed to prevent FW; sharing best practice; and, evaluating progress made over time' (European Commission, 2017). The Platform operates in sub-groups to examine specific aspects and/or questions related to FW. So far, three sub-groups have been established: (1) the sub-group on food donation, that supports the EC on the preparation of EU food donation guidelines for donors and receivers of food surplus and identification of practices, guidelines and rules existing in MS in relation to food donation for sharing with Platform members; (2) the sub-group on action and implementation, that was established to ensure effective sharing of best practises in the area of food waste prevention and to monitor evidence based progress to achieve food waste reduction; and (3) the sub-group on FW measurement, which mandate is to

¹ In similarity to the FUSIONS framework, the term 'Food waste' used in this report include both 'food waste' and 'food losses' using FAO terms

contribute to the development of a common EU monitoring and reporting framework, the development of indicators on FW to be used to effectively monitor implementation of FW prevention policies, the identification of data sets, data collection practices and experiences existing in MS in relation to measurement of food loss and waste in all sectors of the food supply chain, and the discussion of the feasibility and technical possibility of monitoring of food loss and/or resource flow in agro-food industries in the EU (European Commission, 2017).

Furthermore, the EC founded projects 'Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS)' (2012–2016) and 'Resource:Efficient Food and dRink for the Entire Supply cHain (REFRESH)' (2015– 2019) that have been covering various aspects of FW definition, quantification, and mitigation and valorisation strategies (REFRESH, 2016)(FUSIONS, 2014, 2016a, 2016b). The FUSIONS project published in 2016 the 'Food waste quantification manual to monitor food waste amounts and progression' that provides guidelines for MS to account for FW in all sectors of the FSC (primary production, manufacturing, wholesale, food sector and households) (FUSIONS, 2016a).

At the international level, the existing guideline for FW accounting is the 'Food Loss and Waste Accounting and Reporting Standard' (FLW Standard) published in June 2016 by the Food Losses and Waste (FLW) Protocol. The FLW Protocol is multi-stakeholder partnership (e.g. WRI, FAO, WRAP, UNEP, and WDCSD) launched in 2013 with the mission to ensure extensive adoption of the FLW Standard so companies, governments, cities and citizens are informed about FW and engaged in its reduction (FLW Protocol, 2017). Another existing partnership focused on addressing the FW problematic is the Champions 12.3. This coalition of executives from governments, businesses, international organizations, research institutions, farmer groups, and civil society was formed to 'inspire ambition, mobilise action and accelerate progress towards the achievement of the SDG 12.3'. In September 2017, the Champions 12.3 released a guidance on the interpretation of the SDG 12.3, to avoid ambiguity around definitions, life cycle stages, and types of materials, destinations and monitoring indicators to be considered for the achievement of the 12.3 reduction target (Champions 12.3, 2017).

A robust FW accounting system and FW quantification is primordial to enable monitoring FW and measuring distance to FW reduction targets. Such information is necessary to identify the most important FW streams, to define a baseline to monitor FW reduction over time, and to recognise FW flows that may undergo a valorisation process in a circular economy perspective. Over time, various attempts have been made to estimate FW generation using various data sources, such as statistics and direct surveys. Studies accounting FW generated at the EU in all sectors of the FSC (primary production, manufacturing, wholesale, food sector and households) can be found in the literature (Alexander et al., 2017; BIOIS, 2010; Bräutigam, Jörissen, & Priefer, 2014; EUROSTAT, 2017; FUSIONS, 2016a; Monier et al., 2010; Porter, Reay, Higgins, & Bomberg, 2016; van Holsteijn, Kemna, Lee, & Sims, 2017; Vanham, Bouraoui, Leip, Grizzetti, & Bidoglio, 2015). Results, however, are discrepant because of different approaches, e.g. inclusion of inedible fractions of food and type of measurement. Furthermore, each approach presents strengths and weaknesses, which may influence its use for specific purposes.

At present, a consolidated framework for FW quantification in Europe is still an open challenge. This is very concerning because it can lead to misinterpretation of the food system, incomplete FW accounting and consequently, a bad design of intervention policies. Another aspect that is very important to be addressed within the FW context, that only recently has started to receive some attention, is to untangle the drivers of FW generation (Canali et al., 2017). Together with a robust FW account, this will provide a comprehensive understanding of the food system and help designing effective indicators and FW prevention and reduction strategies.

Several challenges are encountered in FW accounting that urge to be addressed. In an overall view, those include raising awareness and inform policy makers, industry and citizens on the amounts of FW, the value of the food wasted and the potential to reduce this FW (why is important to measure FW?). If the different actors understand the

complexity and urgency of the problem, more effort and resources can be allocated to its resolution. There is also the need to define clearly what is food, food waste (edible & inedible parts) & by-products providing a clear answer to the question 'what to measure?'. As mentioned above, harmonized methodologies should be developed including the assessment of the uncertainty (how to measure?). Finally, challenges are faced at the policy intervention level to reduce FW as different types of inter-related strategies need to be developed to prevent, manage and valorise effectively FW (How to reduce FW?). Figure 1 presents an overview of the different levels in which challenges are faced when dealing with FW.

Figure 1. General overview of the different levels of challenges related to Food Waste



To contribute to the development of harmonized and robust FW accounting methodologies and FW quantification, the Joint Research Centre (JRC), bioeconomy unit (D1) organized a technical workshop entitled '*Food waste accounting: methodologies, challenges and opportunities*' with speaker's representative of the main projects related to FW accounting. This workshop was organized back to back with the meeting of the sub-group on FW measurement of the European Platform on FLW. The meeting had the specific objective of updating on the state of play of the proposal to amend the WFD and on the discussion on the target to be defined for SDG 12.3. Both to fulfil the needs of the amended WFD and SDG 12.3, there is a need of systematising and improving FW accounting. Several MSs (Austria, Germany, Spain) and Norway reported their findings regarding the collection of data on FW; DG ESTAT illustrated the results of the FW accounting plug-in exercise; Food and drink Europe presented initiatives to account and reduce FW along the supply chain. At this meeting, JRC D1 presented ongoing research on FW quantification that is being developed within Biomass mandate to JRC, approved by 12 Directorate Generals, on global and European biomass supply and demand on a long-term basis. A full biomass accounting approach is needed and side streams (food to feed, use of food based by-products, etc) should be part of the picture to understand better FW generation, prevention and potential for valorisation, adoption of a territorial or a consumption based perspective in FW accounting, as well as related implications.

The aim of the workshop was to share experiences and perspectives on FW quantification at the European scale, highlighting opportunities and challenges in order to improve FW quantification and ensure better decision support in relation to FW reduction and valorisation. The workshop focused on FW quantification approaches, from the macro scale down to single stages of the FW generation as basis for discussing a way to improve estimations.

This report presents the main issues addressed during the workshop namely existing guidelines for FW accounting (section 2.1), definitions used in FW accounting (section 2.2), system boundaries (section 2.3) and an overview of methodologies used for FW accounting (section 2.4) and existing FW estimates at European level, (section 2.5). Key messages from the workshop are summarized in section 3 and the last section (section 4) presents challenges for FW accounting highlighted by the presentations and the discussions at the workshop. Those challenges define area of improvements that need to be urgently addressed towards the development of a robust FW accounting framework.

2 State of the art in food waste accounting

FW accounting is under a strong development and several open challenges need to be addressed towards a robust and comprehensive FW accounting framework to support decision-making. To know the amount of FW generated along the supply chain and also, to have information on the characteristics of the waste is key to design and support the implementation of policies and strategies that lead to an effective reduction of FW along the supply chain. Although the type of information necessary to intervene at different levels - prevention, management and valorisation – may differ, a holistic view is necessary to better understand dynamics and drivers of FW.

Essential elements to FW accounting are FW related definitions, the system boundaries, the sources of data, the methods used to collect data, and the quantification approach. These aspects are discussed in the following sections.

In the literature, studies can be found reporting FW at different geographic scale (Global, European, National or case representative) and with different breakdown levels (entire supply chain, specific supply chain stage, commodity group or product) as illustrate in Figure 2. However, those studies use distinct FW related definitions, such as the choice of terminology and types of materials and destination associated to each of the terms (Sara Corrado & Sala, 2018; Roodhuyzen, Luning, Fogliano, & Steenbekkers, 2017).

Figure 2. Geographic scale and breakdown level of existing FW accounting studies, Corrado and Sala (2017).

		Supply Chain Breakdown			
		Total	FSC stage	Commodity group and FSC stage	Product per FSC
Geographical scale	Global	Overall FW generation at global scale	FW from one or more FSC stage(s) at global scale	FW from one or more food commodity group(s) per FSC stage(s) at global scale	
	European	Overall FW generation at EU scale	FW from one or more FSC stage(s) at EU scale	FW from one or more food commodity group(s) per FSC stage(s) at EU scale	
	National/regional	Overall FW generation at national/regional scale	FW from one or more FSC stage(s) at national/regional scale	FW from one or more food commodity group(s) per FSC stage(s) at national/regional scale	FW from one or food product(s) per FSC stage(s) at national/regional scale
	Representative case (producer, retailer...)		FW from one FSC stage considering data from a limited number of FSC actors (e.g. retailers, canteens)	FW from one or more food commodity group(s) per a FSC considering data from a limited number of FSC actors (e.g. retailers, canteens)	FW from one or food product(s) per FSC stage(s) considering data from a limited number of FSC actors (e.g. retailers, canteens)

2.1 Existing standard/guidelines for food waste accounting

2.1.1 Food Loss & Waste Protocol (FLW Protocol)

The FLW Protocol is a multi-stakeholder partnership (e.g. WRI, FAO, WRAP, UNEP, and WDCSD), which has developed the standard to report on food loss and waste and associated reporting tools (FLW Protocol, 2017). The 'Food Loss and Waste Accounting and Reporting Standard' (FLW Standard) was published in June 2016. It was developed with the goal to facilitate the quantification of FW (what to measure and how to measure it) and

encourage consistency and transparency of the reported data, enabling the consistent quantification of baselines and tracking of progress towards the UN SDG 12.3 target as well as other targets (FLW Protocol, 2016). It is a global standard that 'provides requirements and guidance for quantifying and reporting on the weight of food and/or associated inedible parts removed from the food supply chain—commonly referred to as 'food loss and waste' (FLW)'. The standard was developed to be used by countries, cities, companies, and other entities enabling them to develop inventories of FLW generated and its destination. These inventories will provide information to design strategies for minimizing FW (FLW Protocol, 2016).

2.1.2 Fusions project

The EC funded project FUSIONS (2012-2016) produced the document 'Food waste quantification manual to monitor food waste amounts and progression' with guidelines for FW accounting. It is a quantification manual coherent with the principles of the FLW protocol, but with the particular objective of guiding European MS in the quantification of FW (FUSIONS, 2016b). It aims to support EU MS in establishing more reliable monitoring and reporting of national FW data at each sector in the FSC. The FUSIONS project team was in close collaboration with the FLW Protocol team, and so the reporting approach for EU MS presented in the FUSIONS quantification manual is fully in line with the general rules of FLW Protocol.

2.1.3 Champions 12.3 Group – Guidance on interpreting SDG 12.3

The document 'Guidance on interpreting SDG 12.3' published in September 2017 provides an interpretation of SDG 12.3 target and it seeks to inform decision makers in government, business, and civil society about what should be considered a 'best practice' understanding of SDG 12.3. The document provides clarifications of which sector should be covered, what is the target for food losses, what type of material should be considered, what destinations count and which indicator should be used. The indicator to be used to monitor countries performance would be 'food loss and waste per capita' (based on a country's population), measured in kilograms/person/year. It would be built on two sub-indicators, one focusing on losses occurring from the farm up to (but excluding) the retail stage of the food value chain (the 'Food Loss Index' presented by FAO (FAO, 2017)), and the other focusing on waste from retail to the point of consumption (a to-be-developed 'Food Waste Index'). FAO has the responsibility for the indicator (Champions 12.3, 2017).

2.2 Food waste definitions

So far, there is not a legal definition of FW neither in food nor in waste European legislation. The first study to comprehensively research FW in the EU was the Preparatory Study on Food Waste across EU 27 (BIOIS, 2010). In this study, FW is described as *'Food waste, composing a large proportion of bio-waste, is waste composed of raw or cooked food materials and includes food materials discarded at any time between farm and fork; in households relating to food waste generated before, during or after food preparation, such as vegetable peelings, meat trimmings, and spoiled or excess ingredients or prepared food. Food waste can be both edible and inedible'*.

A more recent study carried out at the European level was the one developed within the European project FUSIONS, that took a similar approach taking the definition of food as a starting point and counting the material removed from food supply chain as waste: *'Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)'* (FUSIONS, 2016b). At the global level a reference study is the one conducted by FAO -'Global Food Losses and Food Waste: Extent, Causes and Prevention', that considered all side flows meant for food regardless of destination but considered only as FW the edible parts of food meant for humans consumption being lost or wasted (FAO, 2011).

In its resolution of 16 of May 2017 on initiative on resource efficiency: reducing food waste, improving food safety, the European Parliament recommends the Commission and Member States to use the following definition of 'food waste': *'food waste means food intended for human consumption, either in edible or inedible status, removed from the production or supply chain to be discarded, including at primary production, processing, manufacturing, transportation, storage, retail and consumer levels, with the exception of primary production losses'*.

The several FW-related terms and definitions that can be found in the literature are a clear evidence of lack of consensus on terminology and definitions on FW accounting studies. Table 1 summarizes FW related terms and definitions found in the literature presented in the review performed by Roodhuyzen et al. (2017). Different terms are used to refer to FW (e.g. food waste, food wastage, food losses, food losses and waste, food spoilage) and different terms may have the same definition or the same term may have different definitions. Moreover, those definitions encompass focus on different elements: physical/nutritional aspects (e.g. inclusion of edible and non-edible food); place of origin in the FSC; aspects of quality or quantity of the food; behavioural aspects (e.g. food discarded/unwanted even if still edible); intended/actual destination (e.g. discarded food intended for human consumption, discarded food sent to waste management facilities); and, composition. The elements identified in the definitions in Table 1 are presented in the third column.

Table 1. FW related terms and definitions in the literature, adapted from Roodhuyzen et al. (2017).

Reference	Definition	Elements
(Beretta, Stoessel, Baier, & Hellweg, 2013)	<i>Food losses:</i> ‘...food which is originally produced for human consumption but then directed to a non-food use or waste disposal (e.g. feed for animals, biomass input to a digestion plant, and disposal in a municipal solid waste incinerator).’	Intended destination, actual destination
(FAO, 1981); as cited by (Papargyropoulou et al., 2014), and (Parfitt, J., Barthel, M., & MacNaughton, 2010)	<i>Food waste:</i> ‘...wholesome edible material intended for human consumption arising at any point in the FSC [food supply chain] that is instead discarded, lost, degraded or consumed by pests’	Intended destination, place of origin, actual destination
(FAO, 2013)	<p><i>Food loss:</i> ‘a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack of access to markets. In addition, natural disasters play a role.’</p> <p><i>Food waste:</i> ‘food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits.’</p> <p><i>Food wastage:</i> ‘any food lost by deterioration or waste. Thus, the term “wastage” encompasses both food loss and food waste.’</p>	<p>Intended destination, quality, cause</p> <p>Intended destination, cause, actual destination</p>
(Garrone, Melacini, & Perego, 2014)	<p><i>Surplus food:</i> ‘...the edible food that is produced, manufactured, retailed or served but for various reasons is not sold to or consumed by the intended customer.’</p> <p><i>Food waste:</i> ‘...the surplus food that is not recovered to feed people, to feed animals, to produce new products (e.g. jams or juices), new materials (e.g. fertilizers) or energy.’</p> <p><i>Food waste from a social perspective:</i> ‘surplus food that is not used for feeding people.’</p> <p><i>Food waste from a zootechnical perspective:</i> ‘surplus food that is not used for feeding humans or animals.’</p> <p><i>Food waste from an environmental perspective:</i> surplus food that is not re-used or recovered in any form and is disposed of.’</p>	<p>Physical/Nutritional, actual destination</p> <p>Quantity, destination</p>
(Gjerris & Gaiani, 2013)	<i>Food waste:</i> ‘ ... edible food that is discarded, lost, or uneaten ... ’	Physical/Nutritional, actual destination

Reference	Definition	Elements
(Griffin, Sobal, & Lyson, 2009)	<p><i>Generated food waste</i>: 'waste that is unwanted and uneaten (Gallo 1980) by the individuals who acquired the food. Generated food waste may be recovered through composting or donations to food charities.'</p> <p><i>Disposed food waste</i>: 'What remains after these food recovery activities - the food that is actually thrown away'</p>	<p>Behaviour, actual destination</p> <p>Actual destination</p>
(Grolleaud, 2002); as cited by Parfitt et al., 2010	<i>Food loss</i> : 'the decrease in food quantity or quality, which makes it unfit for human consumption.'	Intended destination, Quantity/Quality
(Gustavsson, Cederberg, Sonesson, Van Otterdijk, & Meybeck, 2011)	<i>Food losses</i> : 'the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption.'	Physical/Nutritional, Place of origin
(Kummu et al., 2012)	<p><i>FSC losses</i>: ' ... total losses and waste within the different steps of the FSC [food supply chain] (production, postharvest, processing, distribution, and consumption) ... '</p> <p><i>Food losses</i>: ' ... those in the production, postharvest, and processing of products ... '</p> <p><i>Food waste</i>: ' ... losses during distribution and consumption ... '</p>	Place of origin
(HLPE, 2014)	<p><i>Food loss and waste (FLW)</i>: 'a decrease, at all stages of the food chain from harvest to consumption in mass, of food that was originally intended for human consumption, regardless of the cause.'</p> <p><i>Food losses (FL)</i>: 'a decrease, at all stages of the food chain prior to the consumer level, in mass, of food that was originally intended for human consumption, regardless of the cause.'</p> <p><i>Food waste (FW)</i>: '...food appropriate for human consumption being discarded or left to spoil at consumer level regardless of the cause.'</p> <p><i>Food quality loss or waste (FQLW)</i>: '...the decrease of a quality attribute of food (nutrition, aspect, etc.), linked to the degradation of the product, at all stages of the food chain from harvest to consumption.'</p>	<p>Intended destination, place of origin</p> <p>Intended destination, place of origin Intended and actual destination</p> <p>Quality, place of origin</p>
(Lipinski et al., 2013)	<p><i>Food loss and waste</i>: '...the edible parts of plants and animals that are produced or harvested for human consumption but that are not ultimately consumed by people.'</p> <p><i>Food loss</i>: '...food that spills, spoils, incurs an abnormal reduction in quality such as bruising or wilting, or otherwise gets lost before it reaches the consumer. Food loss is the unintended result of an agricultural process or technical limitation in storage, infrastructure, packaging, or marketing.'</p>	<p>Physical/nutritional, Intended and actual destination</p> <p>Quality, behaviour</p>

Reference	Definition	Elements
	<i>Food waste</i> : 'food that is of good quality and fit for human consumption but that does not get consumed because it is discarded either before or after it spoils. Food waste is the result of negligence or a conscious decision to throw food away.'	Quality, Intended destination, behaviour
(Monier et al., 2010)	<i>Food waste</i> : 'is composed of raw or cooked food materials and includes food loss before, during or after meal preparation in the household, as well as food discarded in the process of manufacturing, distribution, retail and food service activities. It comprises materials such as vegetable peelings, meat trimmings, and spoiled or excess ingredients or prepared food as well as bones, carcasses and organs.'	Place of origin, composition
(Nahman & de Lange, 2013)	<i>Food waste</i> : 'losses that arise before food reaches the end-user (pre-consumer food losses), as well as food that is discarded by consumers (post-consumer food waste). This definition includes both the edible and inedible (peelings, bones, etc.) portions of the waste stream.'	Physical/nutritional, place of origin
(Papargyropoulou et al., 2014)	<i>Food surplus</i> : '... food produced beyond our nutritional needs ...'It consists of 'desired' food surplus that functions to guarantee food security, and undesired excessive food surplus which results in food waste. <i>Food waste</i> : 'a product of food surplus', i.e. a result of a food surplus beyond what is needed to ensure food security.	Quantity
(Parfitt, J., Barthel, M., & MacNaughton, 2010)	<i>Food losses and spoilage</i> : 'food waste post-harvest', 'relate[d] to systems that require investment in infrastructure.' <i>Food waste</i> : 'at later stages of the FSC [food supply chain]', 'generally [related] to behavioural issues.' <i>Post-consumer losses</i> : 'food wasted from activities and operations at the point at which food is consumed.'	Place of origin
(Smil, 2004); as cited by Papargyropoulou et al., 2014, and Parfitt et al., 2010	<i>Food waste</i> : As the definitions by FAO (1981) and Stuart (2009) '... but [including] over-nutrition, the gap between the energy value of consumed food per capita and the energy value of food needed per capita.'	Quantity
(Stuart, 2009); as cited by Papargyropoulou et al., 2014, and Parfitt et al., 2010	<i>Food waste</i> : As the definition by FAO (1981), but '[including] edible material that is intentionally fed to animals or is a by-product of food processing diverted away from the human food chain.'	Physical/nutritional, actual destination
(Quested & Johnson, 2009)	<i>Kitchen waste</i> : 'Food or drink disposed of, including associated inedible material, such as bones from meat, egg shells, and inedible parts of fruit and vegetables, but excludes man-made packaging associated with food or drink, e.g. glass bottles, polymer film, aluminium cans.'	Physical/nutritional, composition

Essential elements of the definition of FW are the selection of material types, the inclusion of inedible parts of food and the destinations of FW (Chaboud & Daviron, 2017). The latter influences the selection of the materials to be included in the accounting. According to Corrado and Sala (2017) two approaches were identified in studies performing FW accounting at the European level: (i) to include food intended for human consumption that was not consumed (Bräutigam et al., 2014; FAO, 2011); (ii) to include only food which is sent to waste management treatments (e.g. anaerobic digestion and composting) (EUROSTAT, 2017; FUSIONS, 2016a; Monier et al., 2010; van Holsteijn et al., 2017).

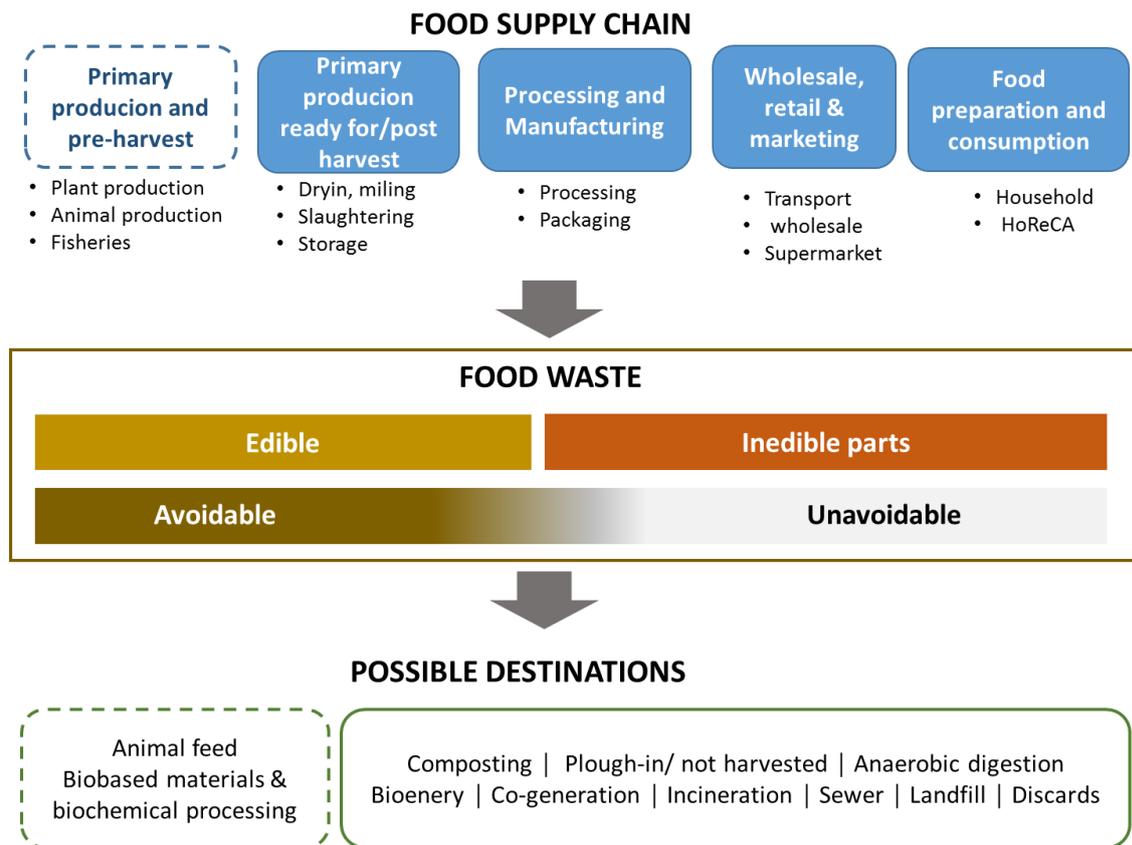
In a general view, the distinction between edible and inedible is mainly related to the physical properties (e.g. eggshell, some fruits skin, animal bones are inedible). Additionally, there is another term and definition that is relevant within the FW accounting context is the distinction between avoidable and unavoidable FW. The former has been defined as the amount of food thrown away because it is no longer wanted or has been allowed to go past its 'best before' or 'expiration' date whereas the latter, as the part of food products that is not edible (Papargyropoulou et al., 2014). However, the distinction between avoidable and unavoidable FW is not always sharp and the subjectivity in food use (behavioural aspects) as well as cultural specificity may play an important role in setting the boundaries. In some countries, for example, animal hide can be eaten while in others it is a by-product used in the leather industry or just considered as waste. This distinction is of particular interest to policy design, as prevention policies should tackle avoidable FW and valorisation policies, unavoidable FW.

A sensitive issue is the inclusion of the fraction of liquid FW, such as milk or beverage. This fraction is generally disposed via the sewer and not captured by quantification approaches based on waste statistics, such as the one adopted by Monier et al. (2010). The fraction of liquid food waste was explicitly considered in the study by FUSIONS (2016a) and van Holsteijn et al. (2017) and was partly accounted by Vanham et al. (2015) who considered FLW of milk and alcoholic beverages and Bräutigam et al. (2014) FAO (2011) and Porter et al. (2016) who included milk FLW (Sara Corrado & Sala, 2018).

2.3 System boundaries

Three central elements for the definition of the system boundaries are the FW definition (type of material, edible/non edible, avoidable/unavoidable), the FSC stage(s) considered, and the FW destination. Figure 3 schematizes these elements based on the FUSIONS framework. The FUSIONS quantification manual recommends the accounting of FW per sector of the FSC divided in the following five sectors: primary production, manufacturing and processing, wholesale, retail and markets, food service, and households. Primary production referring to plant production, animal production, and fisheries, and pre-harvesting is excluded from the systems boundaries (blue dashed line in figure 3). The FUSIONS quantification manual provides recommended approaches to follow in each sector since each of them have significant variations in FW characteristics, waste holders and drivers behind FW generation (FUSIONS 2016b). It defines as FW both edible and inedible parts. Avoidable and unavoidable terms are not specifically considered in the FUSIONS framework and as mentioned above this distinction is not clear. For example, potato skin would be considered inedible according to the nutritional database (Rimestad, Løken, & Nordbotten, 2000) but might be eaten or not according to the recipe. To capture this fact, WRAP introduced the concept of 'possibly avoidable' food (WRAP, 2009), which is food that some people might eat and others might not (the fuzzy area in Figure 3 food waste-avoidable and unavoidable bar intends to illustrate this concept)(De Laurentiis et al). As for possible destinations, flows that can have as destination animal feed and bio-based materials and biochemical processing (green dashed line in Figure 3) are not considered FW within the FUSIONS framework.

Figure 3. Framework defining the Food supply chain and FW adapted from FUSIONS (2016b).

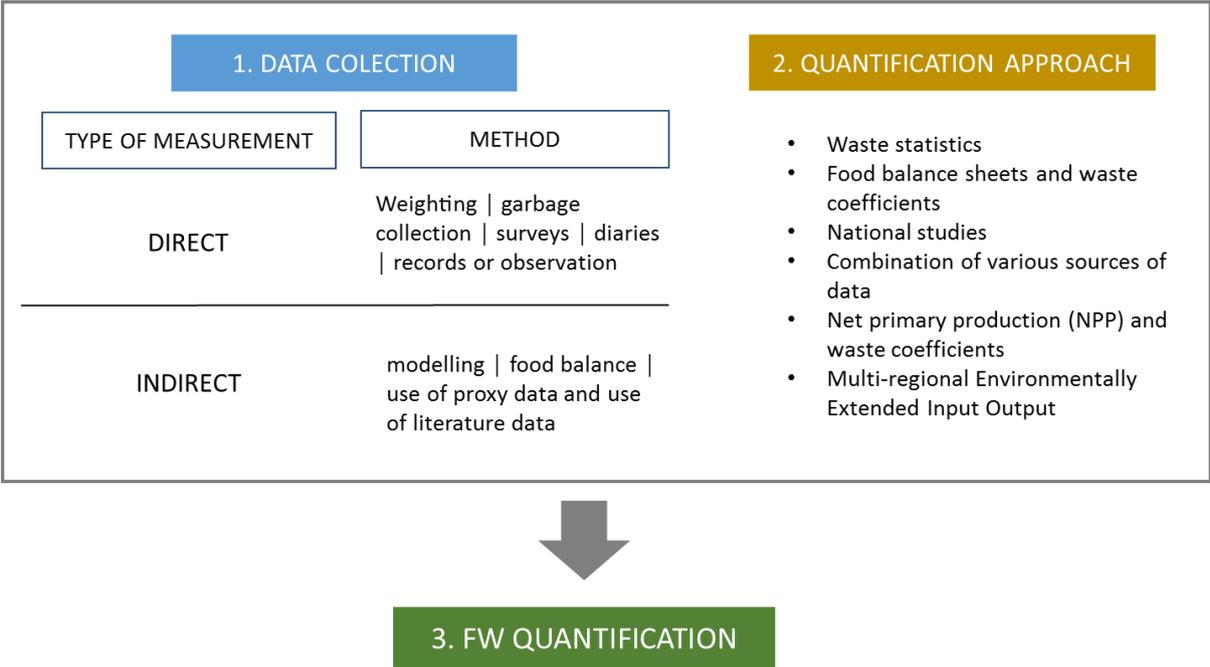


Although FW quantification should consider all the stages of the FSC from agricultural production to consumption, the majority of the studies found in the literature have a narrow coverage of the FSC (Xue et al., 2017). Those that encompassed all the stages of FSC are mainly conducted in industrialized countries like is the case of studies performed at the European level. FW accounting in low income countries and emerging economies such as China, Brazil and India are little explored (Xue et al., 2017). There is therefore low geographic representativeness in FW accounting studies.

2.4 Overview of methodologies

FW quantification can be performed through different data collection and quantification approaches. In turn, data collection can be done through direct or indirect measurements. Figure 4 illustrate the elements included in the FW quantification framework with examples of methods to collect data (1) and quantification approaches (2).

Figure 4. Overview of FW quantification: examples of data collection methods and quantification approaches.



2.4.1 Data collection

Data can be collected through direct or indirect measurements. Direct measurements originate primary data and are generally more resource requiring, and, therefore, applied to single stages of the supply chain, involving a limited number of actors in data collection thus resulting in lack of representativeness. On the contrary, indirect measurements originate secondary data, which best adapt to broader boundaries of analysis and can provide the big picture at the country or region level (Werf & Gilliland, 2017).

Direct measurement methods include waste composition analysis (WCA), weighting, counting, assessing volume, garbage collection, surveys, diaries, records or observation and indirect measurement methods include modelling, mass balance, food balance, use of proxy data and use of literature data can be obtained (Xue et al., 2017). Most of the studies found in the literature are based on indirect measurements quantification approaches in particularly, based only on literature data. In this case, the estimates often rely on each other and are based on a few number of publications (Xue et al., 2017). Table 2 and Table 3 present, respectively, a description of direct and indirect methods.

Table 2. Direct methods used in FW quantification (FUSIONS, 2016b; Xue et al., 2017).

Direct methods	
Waste composition analysis (WCA)	Physically separate, weight and categorise FW. This method may be used to separate FW from a 'waste' stream that includes other material, which is not FW. It may also be used to understand the different materials that make up FW (e.g. types of food categories, or amount of FW that is food versus associated inedible parts).
Weighting	Use of weighting scales to measure the weight of FW. It may or may not include WCA
Counting	Assess (by basic counting, scanning-based approach, or using visual scales) the number of items that originate FW and use the result to determine the weight of FW.
Assessing volume	Measure the space taken up by FW. The volume of FW is subsequently converted into a weight. The method is ideal for liquid FW, but can also be applied to solid and semi-solid material, including solid FW suspended in liquid.
Garbage collection	Separate FW from other categories of residual waste containers to determine the weight and proportion of FW. It may or may not include WCA.
Surveys	Collect information regarding individuals or entities on attitudes, beliefs and self-reported behaviours on FW through questionnaires
Diaries	Collect data from daily records on amount and type of FW for a period of time
Records	Determine the amount of FW based on information collected that is not initially used for FW record (e.g. warehouse record books)
Observation	Assess the volume of FW by counting or using scales with several points to evaluate food leftover by visual method.

Table 3. Indirect methods used in FW quantification (FUSIONS, 2016b; Xue et al., 2017).

Indirect methods	
Modelling	Calculate the amount of FW using mathematical models based on factors that are related to its generation
Mass balance ²	Infer FW by measuring inputs (e.g. ingredients at a factory site) and outputs (e.g. products made) alongside changes in levels of stock and changes to the weight of food during processing (e.g. evaporation of water during cooking).
Use of proxy data	Infer FW using data from companies or statistical agencies (often used for scaling data to produce aggregated FW estimates).
Use of literature data	Use data directly from literature or calculate the amount of FW based on data reported in other publications.

The different methods present advantages and disadvantages in terms of time required, cost, accuracy, objectivity and reliability. The choice of the methods has high influence on the results and it depends on the aim of the study in particular, the intended level of depth, accuracy and reliability, and on the resources available (time, budget). Within the direct methods, weighting and garbage collection provide accurate, objective and reliable information but they are also very time consuming and costly. On the other hand, observation or records require less time and money, but the information is not very accurate as it depends on personal perceptions, the way that data was collected and subjectivity of the observers. Surveys and diaries present a better balance between resources and robustness. Indirect methods are the most used due to their lower cost and time required comparatively to direct methods but their accuracy depends greatly on the quality and representativeness of the original data (Xue et al., 2017).

Methodological gaps have been identified for liquid food going down the drain and waste going to feed since these fractions can be difficult to measure by using the existing methods (Sara Corrado & Sala, 2018).

2.4.2 Quantification approaches

The quantifications approaches followed to quantify FW are varying and they are partly related to the different definitions used. For example, FW may be defined as including or not inedible fractions, or alternative different disposal routes (e.g. sink or dumping). In addition, it can include food intended for human consumption that was not consumed or include only food, which is sent to waste management treatments. According to Roodhuyzen et al. (2017), that reviewed 59 articles addressing FW, the dimensions of difference in FW investigation are:

- i) *Approaches taken to understand and examining FW* (e.g. is the study stage-oriented? does it have a food or impact focus? does it include inedible food? does it include the FW liquid fraction?);
- ii) *Categories of waste* (e.g. FW from a specific phase of the consumption stage; FW type according to avoidability);
- iii) *Measuring methods* (e.g. direct or indirect measurements, use of different units such as weight, cost or nutritional value);
- iv) *Expressing and presenting FW* (e.g. results presented from specific in absolute or relative numbers).

² Mass balance may also be referred to as Material Flow Analysis or Substance Flow Analysis

Although the focus of Roodhuyzen et al. (2017) review was on consumer FW, the aspects here highlighted also influence FW quantification along the FSC.

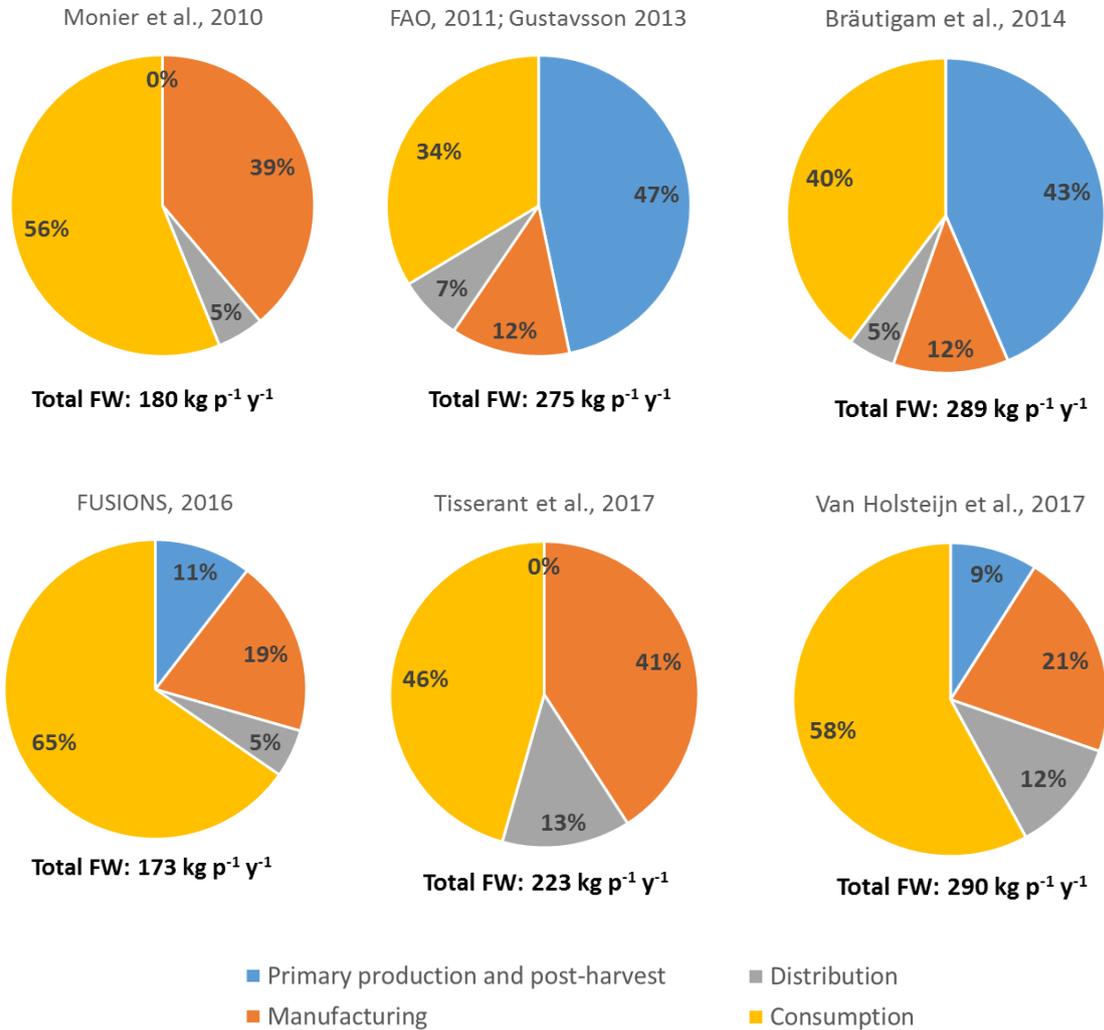
For studies reporting FW at the European level the following approaches were observed (Sara Corrado & Sala, 2018):

- **Waste statistics** based on Eurostat data, in which data on waste contain a breakdown into waste categories according to the 3-digits European Waste Classification for statistical purposes (EWC-Stat) (European Commission, 2010) and according to the Statistical classification of economic activities in the European Community (NACE) (European Commission, 2016) in which they are generated. EWC-Stat is a substance oriented classification and it is linked to the administrative classification List of Wastes (LoW) (European Commission, 2000; EUROSTAT, 2017; Monier et al., 2010)
- **Food balance sheets and waste coefficients** collected from various sources (Bräutigam et al., 2014; FAO, 2011; Porter et al., 2016; Vanham et al., 2015);
- **National studies** Data, collected from part of the European MS and scaled-up to the European level (compliant with the FUSIONS framework) (FUSIONS, 2016a);
- **Combination of various sources of data**, such as FAO, Eurostat, the European Food Safety Authority (EFSA), and scientific literature (van Holsteijn et al., 2017);
- **Net primary production (NPP) and waste coefficients** considering literature data on the global cropland and grassland NPP and on inefficiencies, losses and waste coefficients. Particularly, for the consumption stage they referred to the coefficients reported by FAO (2011);
- **Multi-regional Environmentally Extended Input Output** to build a Multiregional waste input-output model (Tisserant et al., 2017).

2.5 Comparison of FW estimates at the European level

The total FW amount reported (in kg per capita per year ($\text{kg p}^{-1} \text{y}^{-1}$)) in the studies referred in the previous section, as well as the share of FW generated in each stage of the FSC (primary production and post-harvest, manufacturing, distribution and consumption) is reported in Figure 5.

Figure 5. Total FW quantification (in kg per capita per year ($\text{kg p}^{-1} \text{y}^{-1}$) and share of FW generated in each stage of the FSC (primary production, manufacturing, distribution and consumption) at European level reported in different studies.



A wide variation is observed in the results for the total amount of FW with values ranging from $173 \text{ kg p}^{-1} \text{y}^{-1}$ to $290 \text{ kg p}^{-1} \text{y}^{-1}$. Also the share of FW generated in each FSC stage varies. For example, Bräutigam et al. (2014) and FAO (2011) reported a considerable amount of FW generation at primary production and postharvest (43% and 47%, respectively) which was, instead, completely avoided by Monier et al. (2010), Tisserant et al. (2017), and Alexander et al. (2017) or only partly captured in van Holsteijn et al. (2017) and FUSIONS (2016a). This difference may be justified by the fact that waste statistics do not capture the amount of FW not sent to waste treatment. van Holsteijn et al. (2017) found that about the same amount of FW generated at primary production was used as animal feed, but did not account this stream as FW.

Bräutigam et al. (2014), FAO (2011) and FUSIONS (2016a) reported a similar amount of FW for the manufacturing stage, although they included different type of materials: FAO and Bräutigam et al. (2014) accounted only for edible fractions of food, FUSIONS (2016a) included also inedible ones. Monier et al. (2010), Tisserant et al. (2017) and van Holsteijn et al. (2017), who included in the accounting the inedible fractions of food, estimated a similar FW generation at manufacturing stage. Furthermore, van Holsteijn et al. (2017) found that the amount of discarded food sent to animal feed was about one time and half

FW generated at the manufacturing stage. The distribution stage was found to generate a lower amount of FW than the other stages in all the analysed studies. On the contrary, the consumption stage has major contribution.

The discrepancies in the results can stem from the different definition of FW, system boundaries, data sources and quantification approaches. Moreover, the method used for data retrieval (e.g. weighting, surveys, food balance, etc), the representativeness of the data, and the data analysis techniques used (e.g. statistical methods used, assumptions) also contribute to the differences observed.

All the analysed studies made considerations on the reliability and uncertainty of their results, however a quantitative estimation of the uncertainty of FW quantification was reported only by FUSIONS (2016a). The complexity of the food system and the difficulty in comprehensively capture causes and drivers of FW generation make it difficult to capture the different sources of uncertainty (Canali et al., 2017). Nevertheless, efforts should be done to address uncertainty, either methodological or statistical, to obtain more robust values and with low uncertainty. Otherwise, it will be impracticable to measure FW reduction along the years. For example, in the study presented by FUSIONS, some figures (e.g. the case of processing) present an uncertainty in the same order of magnitude of the average value (Table 4).

Table 4. FW quantification figures reported by the FUSIONS study with 95% confidence interval obtained from (FUSIONS, 2016a)

Sector	FW (millions tonnes) with 95% confidence interval	FW (kg per person) with 95% confidence interval
Primary Production	9.1 ± 1.5	18 ± 3
Processing	16.9 ± 12.7	33 ± 25
Wholesale and retail	4.6 ± 1.2	9 ± 2
Food service	10.5 ± 1.5	21 ± 3
Households	46.5 ± 4.4	92 ± 9
Total FW	87.6 ± 13.7	173 ± 27

The European Commission has recently estimated the food waste in 2012 with 161 Kg/capita (European Commission, 2018a, b). However, the figure is not displayed in Figure 5, since no breakdown of the figure into sectors is available.

3 Key messages from the workshop on food waste accounting

The present section summarises key messages emerged during the workshop 'Food waste accounting methodologies, challenges and opportunities', held in Brussels, the 26th September 2017.

3.1 Moving toward an improved food waste accounting: methodologies, challenges and opportunities (Serenella Sala, JRC)

An overview of the ongoing work at JRC on FW accounting was presented, introducing opportunities and challenges to improve FW quantification and enhance its potential for decision support. FW quantification is one of the tasks of the Biomass mandate to JRC, approved by 12 Directorate Generals, on global and European biomass supply and demand on a long-term basis. The definition of a robust accounting of FW can support the achievement of multiple European policy purposes. Indeed, it steers through the definition of prevention measures foreseen by the WFD (European Commission, 2015a), it represents a baseline for monitoring the achievement of FW reduction targets and help in the identification of relevant FW streams to be valorised in a circular economy perspective. Moreover, the specific information on FW characteristics to be captured within the accounting may change according to specific policies questions. Prevention policies, for example, should target avoidable FW but are not applicable to unavoidable fractions, which can be valorised as biomaterial or bioenergy.

A review of studies on FW generation at the European level highlighted important differences between the results. Reasons for such differences may be, e.g., adopted FW definitions, selected system boundaries and source of data. Moreover, estimations done at the large scale do not report a product breakdown enough detailed to support the various policies question. Combining existing top-down data with bottom-up estimations on single products or product-groups will foster the definition of a detailed and comprehensive picture of FW generation.

3.2 Food waste measurement in the EU as part of the circular economy package (Bartosz Zambrzycki, DG SANTE)

Both at global and European levels commitments for FW reduction have been taken: Sustainable Development Goal (SDG) 12.3 and Closing the loop - an EU action plan for circular economy. The Commission's proposal COM (2015)595 amends the WFD and, in compliance with the commitments of SDG 12.3, it requires MS to reduce FW along all the stages of the supply chain, monitor FW generation and report on FW every second year. The proposal for the directive does not report any binding reduction target for MS. Within the interinstitutional negotiation on the amendment to the WFD, the European Parliament proposed a definition of FW to be included in the Directive and asked the Commission to analyse the possibility to include binding targets for FW reduction in the current version of the directive (European Parliament, 2017). The final version of the Directive is expected in early 2018.

The EU Platform on Food Losses and FW, chaired by DG Sante and involving MS and 37 private sector organisations, has the aims of monitoring progress towards the SDG 12.3, defining measure for FW prevention, fostering inter-sectorial cooperation and sharing best practices. Within the Platform, three subgroups has been created, focusing respectively on food donation, FW measurement and action and implementation.

The future monitoring approach for FW generation in EU is expected to be compliant with the FUSIONS framework adapted to the legislative framework, to be based as far as possible on existing reporting and policy frameworks, e.g. European statistics and to be coherent with the FLW Standard . Furthermore, the measurement approach will be aligned with the SDG 12.3 methodology, which will be defined by the Champions 12.3 lead by the

World Resource Institute (WRI). MS are not expected to be asked to adopt a common methodology but to provide a document describing transparently the approach adopted and the quality of data reported.

There are numerous practical challenges identified towards the realisation of a monitoring system for FW, in particular: (i) lack of data at the farm levels; (ii) the accounting of FW in sludges generated at the manufacturing; and, (iii) the monitoring of FW of households and food service, including FW in mixed municipal waste and accounting of food thrown into the sink.

3.3 Food waste – an estimation based on European Statistical System data (Hans-Eduard Hauser, DG ESTAT)

Hans-Eduard Hauser presented a brief description of the plug-in exercise that accounted for FW generated by the MS (on a voluntary basis) according three EWC- Stat codes, disaggregated in 26 List of Wastes (LoW) codes. The main difficulty found was to account for FW at the household level to which correspond three LoW codes, two of them including partly FW and one not having it. For this reason, it was assumed that 25% of household waste is FW, on average (average share, for waste code and estimates at general EU 28 level, not for individual countries). Moisture content of food products changes considerable along the FSC, therefore Mr Hauser asked whether the weight of the fresh food after harvesting should be taken into account, wasted food at the time when it becomes waste, after transport etc. It should be made an estimation of factors to make the weight of FW comparable and the monitoring system should collect the data at the same state.

3.4 Overview of projects on food loss and waste quantification (Karin Östergren, Research Institutes of Sweden, Agrifood and Bioscience)

Karin Östergren presented an overview of three key studies on FW accounting focusing on the scope of the study, the sectors investigated, the source of data and the base year for estimations:

(1) The Preparatory study on food waste across EU27 reported an estimation of FW for 2006 and was based on Eurostat (BIOIS, 2010);

(2) the FAO study on global food loss was focused on FW quantification at global level, with a breakdown in 7 world regions, including an aggregated estimations for Europe and Russia (FAO, 2011). It accounted for the edible fractions of food not consumed by humans, therefore it included the amount of FW used as feed and in other bio-based processes;

(3) the study performed within the Fusions project referred to 2012 and included both edible and inedible parts of food, but did not include side flows used for feeding animals or other bio-based production (FUSIONS, 2016a).

Efforts are being made to improve data quality. High representativeness and transparency are needed in order to improve the statistics and for estimating national or European data. Different methods can be used for FW data collection, either direct (measurement by waste management companies or municipalities, compositional analysis) or indirect (mass balance, questionnaires, statistics from authorities, literature) and their use depends on the FSC stage being analysed. There is not one single method that can be recommended for all applications and there is a need for both top down (macro level) and bottom up (micro level) approaches to be able to produce reliable FW statistics. By simplified methods, using appropriate indicators, data gaps can be filled until better data have been obtained.

FW quantification is a field under strong development and has still a long way to go. More pre-eminent needs are a transparent and standardised way of collecting data and the

collection of high quality data covering all sectors making use of a protocol so that results can be compared along the years and progress on FW savings to be properly accounted. Such protocol has now been agreed upon between major stakeholders and institutions worldwide, which is a milestone. Worth noting is that the protocol leaves it up to the user to define what to consider as food waste in a given situational. Flows not commonly considered as FW (feed, donation) need to be addressed as well to give us the full picture. Edible and inedible parts need to be tackled differently, and thus need to be estimated separately. A transparent framework, consisting of different well defined parts that can be selected and combined in different manners, allows different approaches for estimating FW and side flows leaving the food supply chain of any kind allowing any user to describe which part was used in a consistent way.

Methods on how to convert mass to more relevant indicators are necessary. Besides quantification, other important aspects to be considered when assessing FW includes: environmental impacts, nutritional loss and the costs caused by FW and quality degradation. On the policy side, there is the need to understand the drivers and agree on actions and how to follow up FW reduction (connects to the indicators to be selected). A plan should be developed on how to move forward making use of the knowledge and experience gained by the front-runners on quantification.

3.5 European food waste quantification within the Fusions project (Åsa Stenmarck, IVL Swedish Environmental Research Institute)

Åsa Stenmarck presented an overview of the FUSIONS project. The definition for FW developed within the FUSIONS project is determined by the destination '*Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).*' (FUSIONS, 2016b). In this case, animal feed is not seen as FW. FW includes both edible (e.g. leftovers) and inedible food (e.g. banana peel). The sectors studied were: primary production, processing, wholesale and logistics, retail and markets, food service and households. The methodology followed included: (1) development of Excel-based matrix (questionnaire) supplemented by short guidelines; (2) data collection through questionnaire sent to the MS (either people being contacted, people involved in Fusions or statistical organisations); (3) data processing and analysing consisting in confirmation of values with the MS, evaluation of the data according to different quality thresholds, exclusion of data (extreme values without any explanation of these provided, several or major subsectors not being covered, several or major waste flows not being covered); (4) filling of data gaps; and (5) upscaling of data to obtain EU estimates, through a process for each sector to scale up the data, which did not have a complete coverage of all the 28 European MS. As a first step, a review of on-line literature was undertaken to see if any estimates for FW existed that were not provided previously. Then for those countries where data were missing, these data gaps were filled in by calculating the 'normalised' level of FW (e.g. FW per person or FW per produced amount), based on the countries that did supply data. These normalised levels of waste were then multiplied by the relevant quantity (e.g. population of the countries) to obtain the amount of waste generated for those countries without data. The normalised levels used might also not be fully representative of all countries.

The total FW amounts in the EU-28 for each sector studied and the related uncertainties were presented. Uncertainties for the processing sector are in the same order of magnitude of the average figure reported. The calculated uncertainties for the primary production are considered to be underestimated. One reason for the high uncertainties observed is related to the fact that there is no general FW definition used throughout the EU until now and so, reporting of FW may include inconsistencies among the MS. A common definition used throughout the EU will most certainly decrease the uncertainties of future estimation of FW amounts.

3.6 Food waste quantification using a material flow analysis approach (Gang Liu, SDU University of Southern Denmark)

Gang Liu presentation focused on the use of material flow analysis to quantify FW highlighting that the quantification of FW in a mass balance framework enables a systematic integration and comparison. Moreover, this approach facilitates mass balance check along the supply chain enabling us to know the information that we already have and how good/consistent/reliable it is.

In addition, he presented the main outcomes of an extensive literature review on FW quantification, published by Xue et al. (2017) in which the authors identified the different method that have been used to quantify FW including: literature data and proxy data, food balance, modelling, garbage collection, weighing and observations, diaries and records, and survey. Literature data and proxy data is the most used method and estimates based on literature often relied on each other and pointed to a handful of publications (over a quarter of them cited data from the top 10 cited publications).

Furthermore, Gang Liu and colleagues identified the following gaps in the existing global food loss and waste database:

- i) standardized/harmonized systems and methodology (a variety of systems boundary, definitions and quantification methods);
- ii) more data based on direct measurement (inadequate first-hand data and literature data widely used);
- iii) common reporting framework and databases (outdated data still used);
- iv) more in-depth analysis of FLW at different stages (unbalanced focus on the food life cycle stages); and,
- v) more attention on other countries particularly the case of emerging economies (so far there is a narrow spatial coverage).

3.7 Combining existing data into an overview of total food waste generated in Europe: the perspective of the refrigerators sectors (Freija van Holsteijn, VHK)

Freija van Holsteijn presented a study developed by VHK for the European Commission in the context of Ecodesign and Energy Labelling of household refrigeration appliances. In that study, VHK explored opportunities where improved refrigeration can contribute to FW reduction. The work intended to create a complete and consistent picture of EU's food system and tried to fill the FW data gaps by attempting to make a holistic and closed accounting of the food chain, pulling on a wide range of data sources ranging from general statistics, process technology and specific FW studies. The data was analysed to look for consistency (by using conversion factors to translate between e.g. raw vs processed) and the accounting was done through a closed mass-based accounting system using real weight mass flows and assuming that input equals output in each stage. A comprehensive and detailed Sankey diagram was obtained containing the major food flows.

From this exercise, the authors realized that a system approach is required to assess total FW and that most primary studies only cover a fraction. There are reporting units, system boundaries and partitioning problems. Data availability is fragmented and there is lack of transparency in processing and distribution data. Changes in water content are often not included and data on food consumption often includes end-user waste. More robust data on the actual food intake by end-user would greatly help in assessing the total end-user FW.

The end-user (household and food services) was considered the largest producer of FW with an average 11% of the purchased food being discarded. Half of the end-user waste is

due to not used in time. This and the fact that 2/3 of purchased food is stored in the refrigerator shows the potential of improving food storage conditions. Better and more differentiated refrigeration can double or even triple storage time and so reduce FW due to not used in time.

3.8 The challenge of estimating solid and liquid food waste – experience from studying UK households and food manufacturers (Andrew Parry, WRAP)

Andrew Parry presented an overview of WRAP activities (WRAP has been intensively working in FW accounting and prevention in the UK for over 10 years) and results of FW in the UK considering the FSC stages after farm gate. The majority of waste is generated in the household sector (around 71%) followed by the manufacturing sector (17%). A description of the methodology followed to account for FW in these sectors was presented.

Challenges identified (for the whole food system) include:

- 1) Incentives to measure FW (why to measure): there is a lack of awareness of the amounts of FW, the value of the food wasted and the potential to reduce this, competing priorities and lack of resources;
- 2) Definitions and scope (what to measure): there is lack of clarity around what is defined as food, FW (edible & inedible parts) & by-products;
- 3) Uncertainties around boundaries;
- 4) Methodologies (how to measure): estimates for only a small percentage of FW can be easily extracted from national statistics (<10%) and since most FW is in mixed solid waste or as liquid/sludge, bespoke research is needed to 'extract' FW estimates. Guidance is increasing and many potential methods exist but there is not yet enough experience in applying such guidance. Understanding FW to sewer and on farm are particular methodological challenges.

As for research challenges, there is the need to measure FW at source (vs in a waste stream), develop tools to aid self-reporting, improve the assessment of proxy data and modelling routes. As research and measurement of FW is increasing dramatically, it is critical that guidance and tools are updated in order to reflect progress in understanding and there is the need to establish a robust evidence-base to inform an effective strategy to reduce FW (amounts, food types, reasons). Also, as methods and understanding improve over time, historical data must be re-calculated to be comparable, having in mind that levels of uncertainty and likely changes in FW mean that significant differences may only be detectable at 3-5 year intervals.

3.9 Food waste at retail and public restaurants: quantities and underlying generation dynamics (Mattias Eriksson, Swedish University of Agricultural Science)

Mattias Erikson presented two case studies of FW accounting at a micro-level scale: one for six supermarkets in Stockholm and the other for thirty public restaurants in Sala municipality. The studies were developed to determine FW quantities generated and capture the underlying generation dynamics.

In the supermarkets case study, the analysis was made for the fruit and vegetables (F&V), deli, meat, dairy and cheese departments. F&V presented the higher share among the sub-groups. Nevertheless, the relative percentages varied depending on the unit used, for example F&V had 86% of FW share for results reported in ton/store/years but 48% if reported in CO2e/store/year. Correlation between turnover, shelf life and waste generated were analysed. Longer shelf-life was associated with decrease of waste, but only for products with low turnover.

The public restaurants case study accounted for FW generated at: the receiving point in the kitchen, storage, preparation, dishwasher sieve, serving and plate. It was also performed a categorization of kitchen FW data. Results obtained for the different kitchens ranged from about 12% to 42%. The higher share of waste was serving waste. Factors influencing the FW generated in the different kitchens included the type of kitchen, the portion size and the age and gender of employees.

3.10 The potential of input-output tables in supporting food loss and waste quantification analysis (Jannick Schmidt, 2.0 LCA consultants)

Jannick Schmidt presented how FW can be quantified using EXIOBASE, a global Multi-regional hybrid Input-Output database. Exiobase was developed by harmonizing and detailing monetary and physical supply and use tables (SUTs) for a large number of countries. Accounting for waste is not one of the main purposes of Exiobase. However, SUTs are based on detailed and complete mass balances, therefore, waste is reported in physical SUTs. A peculiarity of Exiobase is that, in contrast with other waste accounting exercises, it reports waste in terms of dry matter, which facilitates the mass balance. FW generation is reported for both productive activities (e.g. manufacturing) and consumptive activities (e.g. hotel/restaurants and households). Furthermore, Exiobase includes environmental extensions, which allow the assessment of the environmental impacts associated with the final consumption of products.

According to Exiobase, in 2011, 63 million tonnes of dry matter of FW were generated globally of which 44% of the waste was produced in households, 33% at manufacturing stage, 16% in restaurants, with the other activities (industries with catering) adding minor contributions.

Advantages of Exiobase are that: it is open for different approaches to quantifying FW; it includes total food production and consumption in all countries; it is integrated in framework fit for life cycle assessment, and it may help evaluating environmental impacts of policy goals and interventions.

The most important/unresolved challenges of FW accounting in Exiobase is the lack of information on FW generation in statistical data that feed SUTs tables.

3.11 Highlights from MACS-G20 Initiative on Food Losses & Waste Reduction (Felicita Schneider, Thünen Institute of Market Analysis)

Ms Schneider presented a brief introduction of the MACS-G20 (Meetings of Agricultural Chief Scientists of G20 Members) and the *MACS Collaboration Initiative on Food Losses and Food Waste*. This *Initiative* was raised at the MACS meeting in Izmir (Turkey) in 2015 and its aim is to concentrate the research and political consulting capacities of members in order to mobilize a noticeable reduction of food losses and waste on a global scale, e.g. by intensifying knowledge and sharing experience or joint funding of research and implementation measures. There was an *Initiative* kick-off workshop in Berlin in June 2017 with 41 participants from 17 countries (13 G20 members, FAO, OECD, EU-Commission among others) to have a comprehensive stocktaking on situation and needs within G20, analyse responsibility of G20 for FW reduction in third countries and options for respective support and interaction among G20 and others. At present, they are collecting ideas from the workshop and getting in contact with international funding schemes and research alliances covering G20 members. Different ideas are being analysed to be implemented, including, for example, cooperation with TempAg (Collaborative Research Network on Sustainable Temperate Agriculture) related to research funding needs in G20 and beyond, or consider post-harvest losses by focusing on stored product protection of staple food. Important international challenges are for example the harmonisation of the definition of

food waste and the system boundaries as well as measuring and reporting towards SDG 12.3 and regional reporting regulations (e.g., EU).

3.12 Socio-economic and territorial drivers of food waste generation in Europe (Luca Secondi, University of Tuscia)

FW is the result of multiple complex factors and behaviours rather than the outcome of a single behaviour therefore it is not an easy task to find a “one fits all” conceptual framework concerning this issue. There are various factors that encourage people to reduce their FW linked to both individual-household and contextual (territorial) levels. In this context, Luca Secondi presented a multilevel framework for dealing with individual behaviour towards FW in order to investigate FW at household level in EU-27 countries. The theoretical framework was developed in a first step considering the most relevant demographic and socio-economic factors associated with individual behaviour FW as emerged by existing literature. Moreover, individual attitudinal variables in order to account for motivation, values and habits was also taken into account. In a second step, variables referring to the context (area) in which individuals reside in order to obtain a comprehensive behavioural model regarding FW generation and prevention was introduced (Secondi, Principato, & Laureti, 2015).

The main conclusions from the study are:

- i) by analysing territorial variability it was possible to identify groups of countries characterized by similar behaviour patterns and therefore targeting them according to the need and the exigency of public policy interventions;
- ii) the importance of the local environment demonstrates the need for considering differences at sub-national level (e.g. diversification of policies according to the extent of urbanization); and,
- iii) the association between eco-friendly industrial production and FW suggests promoting public-private partnerships for addressing FW issues (Secondi et al., 2015).

4 Conclusions: key challenges and the way forward

The key message resulting from the workshop 'Food waste accounting: methodologies, challenges and opportunities' is that a harmonize methodology for FW accounting is not yet defined and there is the need of improving and matching methodological aspects and policy questions as the information needs are different depending on the area of policy intervention (Table 5). For example, policy intervention in FW prevention should focus in the quantification of both avoidable and non-avoidable FW. At the management level an estimation of total amount to be managed (e.g. in waste management plants) is required and in this area the moisture content is a key indicator. Valorisation policies should focus on unavoidable waste and detailed information to better design the valorisation strategy. For example, waste valorisation as energy requires details on composition analysis (e.g. to assess the energy potential) while valorisation as material requires a greater detail of the typology of waste generated, mass over time and quality, location, homogeneity level. Also, another aspect to have in mind is that, in order to understand better FW generation and then act effectively in prevention and valorisation, it is important to have in the picture not just the FW flows, but also side streams such as food to feed, use of food based by-products, etc.

Table 5. Link between areas of policy intervention and related FW accounting needs (adapted from (Corrado et al., 2018))

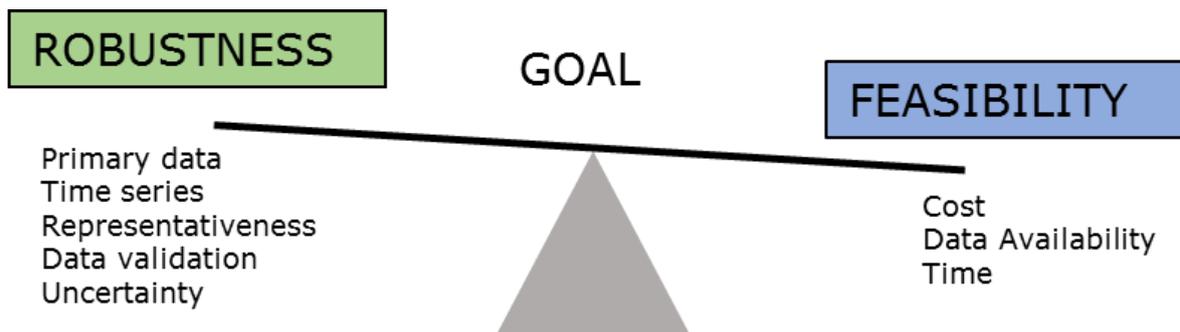
Areas of policy intervention	Accounting needs
Waste prevention	Distinction between avoidable and unavoidable Detailed breakdown in products/products-groups (to prioritise interventions)
Waste management	Estimation of total amount to be managed (e.g. in waste management plants) Moisture content is a key component
Waste valorisation as energy/material	Valorisation as energy requires details on composition analysis (e.g. to assess the energy potential) Valorisation as material requires detail on the typology of waste generated, seasonality, location

Within the methodological realm, several challenges were identified that need to be addressed to ensure robust FW accounting to support policy development in relation to FW prevention, management, and valorisation. The more pre-eminent are:

- **Clear and consensual FW definition.** This involves defining clearly and in standardized way the aim, definitions and terminology (edible/inedible and avoidable/unavoidable), system boundaries, and, units of measurement. This would enable the comparison of existing data across countries, commodities, and FSCs, which would further help exploring patterns and driving factors of FW generation.
- **Improve data quality.** Although the literature on FW quantification is growing, there is lack of original data and existing studies often relied on each other and pointed to a handful of publications. The data should be collected in a transparent and standardised way and covering all sectors making use of guidelines provided in documents like the (FLW Protocol, 2016) or the (FUSIONS, 2016b). To define a

robust and comprehensive picture of FW generation, on one hand there is the need of collecting more primary data, to better depict the variability which is characterising FW generation along the FSC and the year. On the other hand, costs to collect primary data could be too high to be afforded, therefore a compromise between reliability and representatives of data, and economic commitment should be found. A balance should exist between the necessary robustness of the study and the feasibility of data collection. This balance is intimately related with the goal of the study as illustrated in Figure 6. A useful development may be the identification of methods for accounting which balance costs and robustness/representativeness of the results.

Figure 6 –Aspects to be considered to balance robustness and feasibility.



As no direct (primary data) or indirect (secondary data) method is satisfactory by themselves, a way to overcome this issue could be, as suggested by Xue et al. (2017), to develop an integrated approach by coupling direct with indirect measurements. Top-down studies performed at the national and regional levels to determine the magnitude of the problem (more for policy-making and strategy-setting) would be done using statistics-based estimation of FW while bottom-up studies, realized at the ground level to analyse in-depth FW drivers and affecting factors so as to design effective intervention steps, would be built based on first-hand measurements.

- **Water accounting.** Methodological approaches accounting of liquid waste specifically related to water content of food, to water embodied in food during preparation and to FW down the drain in sewage are lacking. Moreover, the amount of water embedded in food products may change considerably along the food supply chain and within seasons, e.g. due to temperature variations and cooking practices. Direct measurement of FW, therefore, can be biased by moisture content variations and, in existing studies, this element has been barely addressed. Furthermore, from existing FW definitions is not always clear whether mass lost as water should be considered waste and how to account for mass gained due to absorption of water, e.g. during cooking.
- **Uncertainty and variability.** Uncertainty (both statistical and methodological) and spatial and temporal variability of FW in all the FSC stages are rarely addressed in the literature. Research is necessary to identify systematically types and sources of uncertainty and variability within the FW accounting framework and provide guidelines and tools to assess them.
- **Territorial vs consumption approach.** Estimation of FW are generally based on a territorial approach, allocating waste generation to the geographical area where they are generated, rather than to the one where they are consumed, as in a consumption-based approach. The territorial-based approach is adopted in the studies based on input-output tables and may represent a valuable approach for

considering the FW 'embedded' in exported food products. This could be particularly relevant for productions highly site-specific and with a high waste rate, such as fish filets produced in European Nordic countries and exported all around Europe. On the contrary, consumption-based approach is not highly relevant when the aim of the accounting is to estimate actual amount of FW to be managed or valorised.

- **Policy development and implementation.** Register and monitor FW towards FW related targets, requires the identification of the adequate indicator(s). The definition of an indicator requires the choice of the baseline year on which changes in FW generation or management will be monitored. Additionally, the way in which the target is expressed can be critical if we consider that halving FW for a country already virtuous could be extremely challenging. Other important elements of the indicators are: i) the choice of the unit of measure, such as mass, economic value or greenhouse gas emissions, which are not directly correlated; ii) the reporting either in absolute terms or in percentage; iii) the reference to the total mass of FW or only to the avoidable.
- **FW drivers.** The analysis of drivers behind FW generation is an open challenge of extreme relevance for both designing properly the framework for primary data collection and defining effective reduction strategies. Generation of FW is influenced by different factors, namely behavioural, technological, product-related, legislative and societal, and their relevance can be highly context-specific and not always predictable (Canali et al., 2016; Secondi et al., 2015). Roodhuyzen et al. (2017), for example, highlighted that different factors can have contradictory effects on FW generation according to the context in which the study is carried out and claimed for more casual insight analyses to explain contradictions. Therefore, interpreting drivers of FW generation is still an open challenge.

4.1 Envisioning the future in food waste accounting

The development and improvement of FW accounting at the European level and particularly in each MS could be reached by having a continuous update of bottom-up and top-down studies. These studies should be performed following existing guidelines such as the FLW standard or the FUSIONS quantification manual (both were developed based on the same principles). The starting point for the top-down study could be a high level map of FW generated in each sector per MS, for example a Sankey diagram as that developed by van Holsteijn et al. (2017) at the European level (Sankey graph illustrated in Figure 7) built initially with available statistical data and coefficients. The MS would then update this map with country specific data and coefficients whenever available. Furthermore, this map could be designed allowing breakdown levels. Following the example presented in Figure 7, one could break down to specific products linked to possible policy interventions (prevention, management or valorization). Here data would be collected at a micro-level in a bottom-up approach. Following example in Figure 7, the product could be for example tomato, which waste originated at the manufacturing stage can be valorised through the extraction of anti-oxidants and is therefore, of particular interest to map.

As research and measurement of FW is increasing dramatically it is critical that guidance and tools are updated to reflect progress in understanding and there is the need to establish a robust evidence-based effective strategy to reduce FW (amounts, food types, reasons). Also, as methods and understanding improve over time, historical data must be re-calculated to be comparable, having in mind that significant differences may only be detectable at 3-5 year intervals. Figure 8 illustrates the integration of data quality improvement and methodological development in FW accounting along time.

A valuable development would be to add a LCA perspective to the FW framework to capture impacts associated with FW along the product life cycle. This could be done by attributing a 'waste intensity' to specific products or group of products generated in each stage of the FSC. Moreover, it is also relevant to know where we want to go and design the best possible

scenarios (e.g. towards zero landfill, less resource dissipation, greater valorisation) and assess them in a LCA perspective. This should be done having in mind the existence of paradoxes, such as having solution or innovations to reduce FW or to have food lasting longer, which may imply environmental impacts beyond the benefits stemming from the FW prevention/reduction.

Figure 7. Conceptual design of top-down and bottom-up FW assessment in Member States (MS).

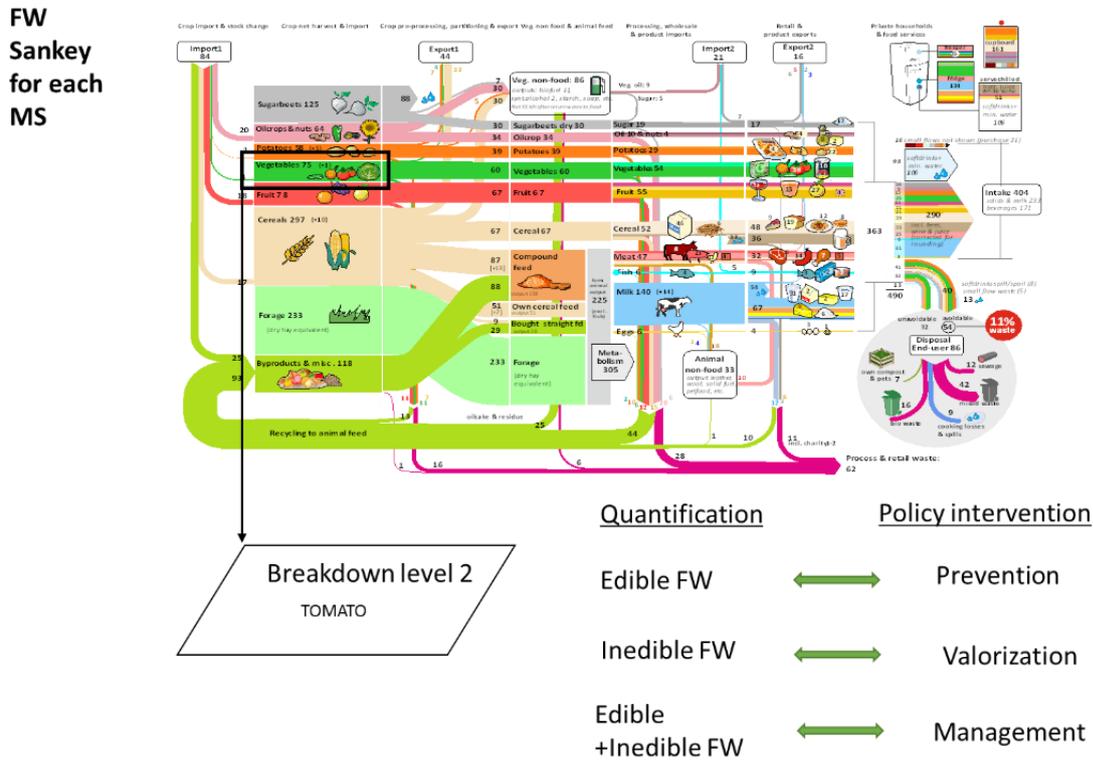
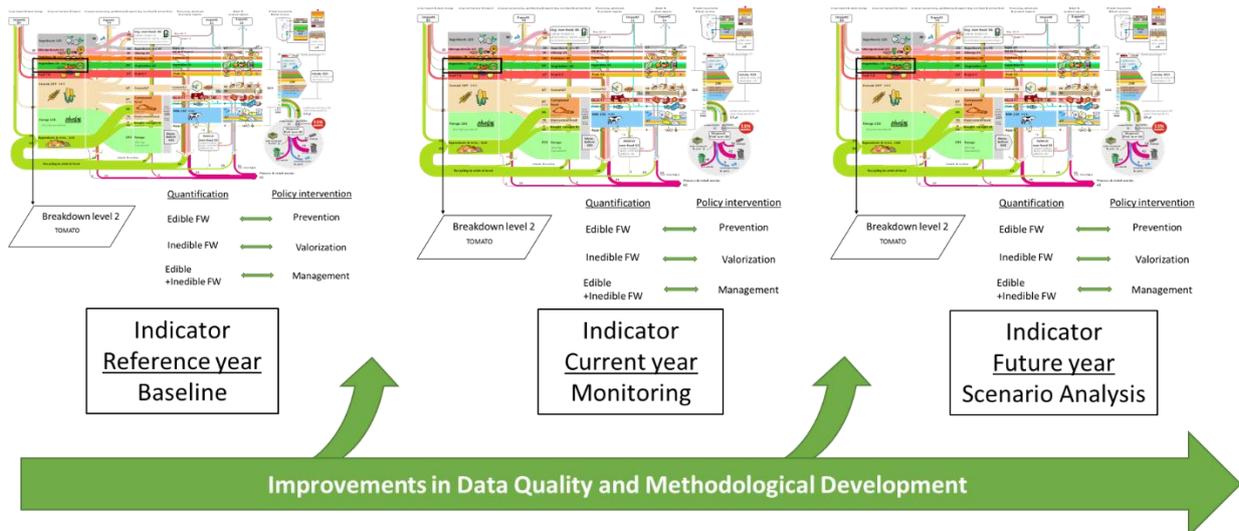


Figure 8. Integration of data quality improvement and methodological development in FW accounting.



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List of abbreviations and definitions

EC	European Commission
EWC-Stat	European Waste Classification for statistical purposes
FAO	Food and Agricultural organization
FLW	Food Loss and Food Waste
FSC	Food Supply Chain
FW	Food waste
FUSIONS	Food Use for Social Innovation by Optimising Waste Prevention Strategies
JRC	Joint Research Center
LCA	Life Cycle Assessment
LoW	List of Waste
REFRESH	Resource: Efficient Food and dRink for the Entire Supply cHain
SDG	Sustainable Development Goal
UN	United Nations
UNEP	United Nations Environment Programme
WCA	Waste Composition Analysis
WDCSD	World Business Council for Sustainable Development
WFD	Waste Framework Directive
WRI	World Resource Institute
WRAP	Worldwide Responsible Accredited

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Annexes

Annex 1. Workshop agenda



EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate D – Sustainable Resources
Bio-Economy Unit

Workshop

Food waste accounting: methodologies, challenges and opportunities

26th September 2017, Thon Hotel, Avenue du Boulevard, 27 Brussels

In Europe, about 89 million tonnes of food are lost or wasted along the supply chain, representing a considerable burden for the environment and a great inefficiency of the food system. Having committed to the United Nations Sustainable Development Goal 12.3, European member states are expected to halve food waste at retail and consumer levels and to reduce food waste along the supply chain within 2030. Furthermore, initiatives aimed at fostering food waste reuse, minimising the dissipative use of resources, are advocated by European policies on circular economy and bio-economy.

Reliable estimations of food waste streams are, therefore, a fundamental starting point for identifying possible areas of intervention, and to monitor progress over time.

At present, in Europe a consolidated framework for food waste quantification is still an open challenge. Over time, various attempts have been made to estimate food waste generation using various data sources, such as statistics and direct surveys. Results, however, may not converge because of different approaches, e.g. inclusion of inedible fractions of food and type of measurement. Furthermore, each approach presents strengths and weaknesses which may influence its use for specific purposes.

The aim of the present workshop is to share experiences and perspectives on food waste quantification at the European scale, highlighting opportunities and challenges in order to improve food waste quantification and ensure better decision support in relation to food waste reduction and valorisation.

The workshop will focus on food waste quantification approaches, from the macro scale down to single stages of the food waste generation as basis for discussing a way to improve estimations.

Workshop Agenda

09.00 - 09.30 Arrivals and registration

09.30 - 09.50 Serenella Sala - JRC

Moving toward an improved food waste accounting: opportunities and challenges to better decision support

09.50 - 10.10 Bartosz Zambrzycki - DG SANTE

Food waste measurement in the EU as a part of Circular Economy package

10.10 - 10.30 Hans-Eduard Hauser - DG ESTAT

Food waste – An estimation based on European Statistical System data

- 10.30 - 11.00 **Karin Östergren - Research Institutes of Sweden, Agrifood and Bioscience**
Overview of projects on food loss and waste quantification
- 11.00 - 11.20 *Coffee break*
- 11.20 - 11.40 **Asa Stenmarck - IVL Swedish Environmental Research Institute**
European food waste quantification within the Fusions project
- 11.40 - 12.00 **Gang Liu - SDU University of Southern Denmark**
Food waste quantification using a material flow analysis approach
- 12:00 - 12.20 **Rene Kemna - VHK**
Combining existing data into an overview of total food waste generated in Europe: the perspective of the refrigerators sectors
- 12.20 - 12.45 **Discussion**
- 12.45 - 14.00 **Lunch**
- 14.00 - 14.20 **Andrew Parry - WRAP**
The challenge of estimating solid and liquid food waste – experience from studying UK households and food manufacturers
- 14.20 - 14.40 **Mattias Eriksson - Swedish University of Agricultural Science**
Food waste at retail and public restaurants: quantities and underlying generation dynamics
- 14.40 - 15.00 **Jannick Schmidt – 2.0 LCA consultants**
The potential of input-output tables in supporting food loss and waste quantification
- 15.00 - 15.20 **Felicita Schneider - Thünen Institute of Market Analysis**
Highlights from MACS-G20 initiative on Food Losses & Waste Reduction
- 15.20 – 15.40 **Luca Secondi - University of Tuscia**
Socio-economic and territorial drivers of food waste generation in Europe
- 15.40 – 16.15 **Discussion and outlook**

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