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Review of studies on food waste accounting at Member State level

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Abstract

The economic, environmental, and social impacts of food waste are significant and its reduction is urgent. Target 12.3 of the Sustainable Development Goals advocates for a 50% reduction of the per capita global food waste at the retail and consumer level by 2030, and for a reduction in food losses along production and supply chains including post-harvest losses. The European Commission, besides committing to achieve the SDG 12.3 target, has identified food waste as one of the priority areas of the European Circular Economy Action Plan. To act on food waste reduction, it is essential for Member States (MSs) to know what are their current levels of food waste. It is equally relevant that this information is gathered using a common quantification approach. To understand the state of play in food waste quantification in the MSs, a literature review of existing studies quantifying food waste in the MSs was conducted by the European Commission Joint Research Centre in support to the activities of the subgroup 'Food waste Measurement' of the EU Platform on Food Losses and Food Waste. This review was carried out in light of the elements defined in the delegated act that has been adopted by the Commission on 3rd May 2019, establishing a common methodology and minimum quality requirements for the uniform measurement of level of food waste generated in MSs. Aspects analysed included: (i) the definition of food waste used; (ii) the scope and boundaries of the study; (iii) the accounting methodology, including the measurement method(s) used; (iv) the amount of food waste estimated and its final destination(s); (v) additional indicators (e.g. economic, environmental, social) reported; and, (vi) gaps and challenges reported in the studies. In total, 48 studies were analysed. The review highlighted that current data on food waste quantification at MS level is scarce. Although some MSs have been developing work in this area, others have not yet conducted any study quantifying food waste. In general, the studies were carried out using different food waste definitions and following different quantification approaches, which makes their comparison very limited.

1 Introduction

According to the FUSIONS[1] report, around 88 million tonnes of food are wasted annually in the EU, with associated costs estimated at 143 billion euros (FUSIONS, 2016a). In 2015, more than 150 world leaders met in New York and adopted the 17 Sustainable Development Goals (SDGs) (UN, 2015). Under the SDG 12 – Responsible Consumption and Production, target 12.3 was set: 'by 2030 halve per capita global food waste at the retail and consumer levels, and reduce food losses along production and supply chains including post-harvest losses'. The European Commission (EC), besides committing to achieve the SDG 12.3 target, has identified food waste as one of the priority areas of the European Circular Economy Action Plan (European Commission, 2015). To foster cooperation with stakeholders, in 2016 the EU Platform on Food Losses and Food Waste (FLW) was established with the overall mission of supporting the Commission, Member States (MSs), and all actors in the food supply chain (FSC) in achieving the SDG 12.3 target without compromising food safety, feed safety and/or animal health. The Platform is coordinated by DG SANTE and is structured in four subgroups respectively dealing with 'Food Donation', 'Food Waste Measurement', 'Action and Implementation', and 'Date Marking'.

The amendment to Directive 2008/98/EC on Waste (European Commission, 2018) introduced the definition for food waste i.e. 'food waste' means all food[2] as defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council (European Commission, 2002) that has become waste[3]. It also obliges MSs to monitor the generation of food waste and to take measures to limit its generation. However, current waste statistics do not provide information on food waste. In addition, there is a lack of a consolidated framework for food waste quantification in the EU. Such framework is of utmost importance for the actors of the food supply chain, organizations and governments to implement and monitor effective reduction strategies (Corrado & Sala, 2018), enabling the definition of baselines and monitoring performance towards target 12.3. To fill this gap, the EC is about to release a delegated act establishing a common methodology and minimum quality requirements for the uniform measurement of food waste generated in MSs (European Commission, forthcoming). This document clarifies the scope of the measurement of food waste and defines the actual requirements for measurement. The delegated act was developed on the basis of the outcome of the work of the EU Platform on Food Losses and Food Waste (in particular its subgroup 'Food waste Measurement'). In the preparation of the Delegated Decision the Commission was assisted by Expert Group on Food Losses and Food Waste composed of experts from Member States (http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3189).

Beside the delegated act, two other documents exist that provide guidelines for food waste quantification. One is the Food Losses and Waste Standard (FLW Standard) (FLW Protocol, 2016) published in 2016 by the Food Losses and Waste Protocol, providing requirements and guidance for quantifying and reporting on the weight of food and/or associated inedible parts removed from the FSC. This standard was developed to facilitate the quantification of food waste (what to measure and how to measure it) and to encourage consistency and transparency of the reported data, enabling the consistent quantification of baselines and tracking of progress towards target 12.3 as well as other targets. It was developed to be used by countries, cities, companies, and other entities enabling them to develop inventories of food waste generated and its destination (FLW Protocol, 2016).

[1] FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies) was a EU-funded project carried out from 2007 to 2012 on the estimation of food waste generation in the EU.

[2] 'food' (or 'foodstuff') means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans (European Commission, 2002)

[3] 'waste' means any substance or object which the holder discards or intends or is required to discard; (European Parliament and Council, 2008)

The other document is the 'Food waste quantification manual to monitor food waste amounts and progression' published in 2016 under the FUSIONS project. This is a quantification manual coherent with the principles of the FLW Standard, but with the particular objective of guiding MSs in the quantification of food waste (FUSIONS, 2016a). The main aim of this manual is to support EU MS in the monitoring and reporting of national food waste data at each sector of 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 Standard (Caldeira et al., 2017).

The use of such documents is expected to reduce the high discrepancies observed in food waste quantification studies covering the same region as was observed in the review carried out by Corrado & Sala (2018). According to the authors, discrepancies in the results are because the studies were built on different quantification approaches and data sources, limiting the comparison of results and the monitoring of food waste generation overtime. In their review, Corrado & Sala (2018) analysed studies developed at global scale and EU level. The first study quantifying food waste at global level reporting results for 7 regions, including Europe, was done by the Food and Agriculture Organization of the United Nations (FAO) FAO (2011). Other studies estimating food waste amounts at global level were developed by Porter et al. (2016), Alexander et al.(2017), and Tisserant et al. (2017). At EU level, studies were done by Monier et al. (2010), Bräutigam et al. (2014), Vanham et al. (2015), FUSIONS (2016b), and Kemna et al. (2017). Among these, some have provided disaggregated results for EU countries. A short description on the approach followed in these studies follows.

The study done by Monier et al. (2010) was the first attempt to assess the amount of food waste in the EU and it was based on data collected by Eurostat, in which data on waste contain a breakdown into 3 digit-waste categories as reported in the European Waste Classification for statistical purposes (EWC-Stat)(European Commission, 2010). EWC does not disaggregate the share of FOOD WASTE, which is, to different extents, included in the waste categories together with other bio-waste streams, such as garden and park waste. Monier et al. (2010) dealt with this issue refining or substituting Eurostat numbers with national data, when available. This study reports data from 2006.

Bräutigam et al. (2014) adopted FAO's approach, considering the same waste coefficients, except for the 'postharvest handling and storage' stage, calculated for each of the EU27 countries based on data reported in the FAO Food Balance Sheets (FBS). FAO (2011) estimated the amount of edible food waste combining data on food commodities reported in the FBS and food waste percentages presented in Gustavsson et al. (2013) from various sources, e.g. scientific literature and national authorities. The study by FAO (2011) was carried out at the global scale, including a breakdown in 7 world regions. Data in this study refers to 2007.

The report by FUSIONS (2016b) was a deliverable of the EU-funded FUSIONS project on the estimation of food waste generation in the EU. FUSIONS (2016a) considered data compliant with the FUSIONS framework, collected from part of the European Member States and scaled-up to the European level. Quality criteria were established for the inclusion of results in the overall assessment of food waste generation at EU level. Data on food waste reported in this study is from 2012.

Another review on food waste quantification studies was carried out by Xue et al. (2017) The authors examined 202 publications which reported food loss and waste data for 84 countries and 52 individual years from 1933 to 2014. The main findings of the study are that most of the studies were conducted in a few industrialized countries (e.g., the United Kingdom and the United States), and more than half were done based only on secondary data, which signals high uncertainties in the existing global food losses and waste database. A statistical analysis was performed for the food losses and waste quantified for the different stages of the FSC per food commodity group showing high variability in the results. Building on the review studies abovementioned and in light of the elements defined in the delegated act, a literature review of existing studies quantifying food waste at MS

level was conducted by the European Commission Joint Research Centre (EC-JRC) in support to the activities of the subgroup 'Food waste Measurement' of the FLW EU Platform. The main goals of this review are twofold:

I. To identify existing gaps and limitations in food waste accounting at MS level, and
II. To analyse the food waste accounting approaches employed by each country and the comparability of these studies.

The studies considered include both those developed by the governments and those developed by non-governmental or scientific institutions. The analysis covers the following aspects:

- Food waste definition used, including if any of the existing guidelines for food waste accounting was used;
- Scope and boundaries of the study;
- Accounting methodology, including the measurement method(s) used;
- Information on the amounts of food waste estimated and final destination;
- Additional indicators (e.g. economic or environmental) reported;
- Identification of gaps and challenges.

This report presents the results of the review carried out. The findings herein presented aim: (1) to inform the EC on existing food waste measurement exercises at MS level, identifying major gaps or difficulties (related to the requirements of the delated act), and (2) to support the development of guidelines on how the data gaps could be filled and how to improve data coverage and comparability across the EU. The report is divided in five sections, including this introduction (Section 1). Section 2 presents the review methodology used, including (i) the sources for the collection of studies and the rationale for their selection, and (ii) the elements analysed in the studies. Results are presented in Section 3, followed by a discussion (Section 4). Finally, Section 5 presents the conclusions of the exercise, summarizing the main findings.

2 Review methodology

This section describes the sources used for the collection of studies quantifying food waste at MS level and the rationale used in their selection.

The focus of the selection was on studies providing a quantification of food waste for EU MSs.

2.1 Collection of studies and rationale for selection

The review of studies was conducted via both scientific and grey literature, and it was complemented by input obtained directly through the EU Platform on FLW.

The review of the scientific literature was performed using the bibliometric database Scopus (www.scopus.com) using the keywords 'food loss', 'food waste' and 'food wastage' and the names of all the different EU countries (e.g. 'France' or 'Spain') as well as and their adjectives such as 'French' or 'Spanish'.

Furthermore, since a large amount of data on food waste is reported within scientific reports, the grey literature on the topic was also explored, starting from the analysis of the reference lists of scientific papers that have performed a review on studies quantifying food waste such as Xue et al. (2017) and Corrado & Sala (2018). Additionally, a search in google scholar and google using the same keywords mentioned above was done, and a consultation of The Food Waste Atlas™ from WRAP to obtain additional reports and food waste data from the EU MSs.

Finally, the representative of each MS participating in the meetings of the Expert Group on Food Losses and Food Waste was contacted to provide studies existing in their country.

In total 294 studies were collected. To streamline the review, studies to be analysed in detail were selected following these criteria:

- at least one study for each country,
- studies covering the entire food supply chain,
- the most updated studies, preferably from 2015.

If for one country the last two criteria were not fulfilled, studies before 2015 and covering partially the FSC were also considered. These criteria were used to select studies conducted at national level. However, to fill gaps for some countries and/or stages of the FSC, studies conducted at regional level or that considered a small sample (e.g. the activities of a supermarket).

In total, 48 studies were analysed in detail focusing on the elements described in section 2.2. A code ('X_#') was attributed to each study, where X is the code of the country (Table 1) and # the number of study for that country. Additionally to the MS countries referred in Table 1, the analysis also included studies from Norway (NO).

Table 1. Codes of the countries (Eurostat, 2019).

Country	Code	Country	Code	Country	Code	Country	Code
Belgium	BE	Greece	EL	Lithuania	LT	Portugal	PT
Bulgaria	BG	Spain	ES	Luxembourg	LU	Romania	RO
Czechia	CZ	France	FR	Hungary	HU	Slovenia	SI
Denmark	DK	Croatia	HR	Malta	MT	Slovakia	SK
Germany	DE	Italy	IT	Netherlands	NL	Finland	FI
Estonia	EE	Cyprus	CY	Austria	AT	Sweden	SE
Ireland	IE	Latvia	LV	Poland	PL	United Kingdom	UK

This review considered as well the studies reported in Chapter 1, namely Monier et.al. (2010), Bräutigam et al. (2014), and FUSIONS (2016b), to complement the studies carried out at MS level.

2.2 Elements analyzed

The following elements were analysed in the selected studies:

- **Food waste definition** used in the study; including the use of the terms edible/inedible and/or avoidable/ unavoidable, and if any of the existing guidelines for food waste accounting (Fusions Quantification Manual (FUSIONS, 2016a) or Food Loss and Waste Accounting and Reporting Standard (FLW Standard) (FLW Protocol, 2016) had been followed;
- **Scope and boundaries of the study**, identifying:
  (i) which stages of the FSC were covered, i.e. primary production (PP), processing and manufacturing (P&M), retail and other distribution of food (R&D), restaurants and food services (RFS), and households,
  (ii) what was the temporal and geographic scope, and
  (iii) which food commodity groups were included in the study.
- **Accounting methodology**, including the quantification method used: Direct methods – weighing, waste composition analysis (WCA), surveys, diaries, records, observation, and/or Indirect methods – modelling, mass balance, proxy or literature data (see box 1 for a description of the methods);
- **Amounts of food waste quantified** in each study per stage of the FSC;
- **Food waste destinations** e.g. animal feed (for studies which count such use as 'waste'), energy use, composting, landfill;
- **Liquid waste,** whether or not it was quantified and if so, how;
- **Assessment of additional indicators** e.g. economic, environmental, social;
- **Gaps and challenges** reported in the studies.

Box 1. Description of the type of methods obtained from Caldeira et al. (2017)

Direct methods

Weighing - Use of weighting scales to measure the weight of food waste. It may or may not include waste composition analysis.

Waste Composition Analysis (WCA) - Physically separate, weight and categorise food waste. This method may be used to separate food waste from a 'waste' stream that includes other material, which is not food waste. It may also be used to understand the different materials that make up food waste (e.g. types of food categories, or amount of food waste that is food versus associated inedible parts).

Surveys - Collect information regarding individuals or entities on attitudes, beliefs and self-reported behaviours on food waste through questionnaires.

Diaries - Collect data from daily records on amount and type of food waste for a period of time.

Records - Determine the amount of food waste based on information collected that is not initially used for food waste record (e.g. warehouse record books).

Observation - Assess the volume of food waste by counting or using scales with several points to evaluate food leftover by visual method.

Indirect methods

Modelling – Calculate the amount of food waste using mathematical models based on factors that are related to its generation, using for example waste coefficients.

Mass balance - Infer food waste 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).

Proxy data - Infer food waste using data from companies or statistical agencies (often used for scaling data to produce aggregated food waste estimates).

Literature data - Use data directly from literature or calculate the amount of food waste based on data reported in other publications.

3 Results

The studies analysed refer to food waste quantification in the different EU countries over different years. Table 2 presents the list of studies analysed per country and the year to which the data reported refers to, identifying those studies carried out at regional level (green cells) and the case studies (grey-cells). An additional study considered that is not included in the table because it reports aggregated results for different countries is the quantification of food waste in TESCO activities in Central Europe, - Czech Republic, Hungary, Poland and Slovakia, designated in this report as CE_1[4]. The following sections present the results of the analysis of the studies selected in light of the elements described in section 3.2.

Table 2 List of the selected studies analysed. The green cells identify studies realized at regional level and the grey cells studies that considered a small sample.

Code	Entity developing the study	Year/s of measurement	Reference
AT_1	ECR Austria – Efficient Consumer Response & ABF-BOKU	2014	Hrad, M., Ottner, R., Lebersorger, S., Schneider, F. and Obersteiner, G., 2016. Vermeidung von Lebensmittelabfall in Gastronomie. *Beherbergung und Grosskuchen-Erweiterung weitere Betriebe'Endbericht im Auftrag von Tatort nachhaltige Projekte GmbH, Wien, Osterreich*, *35*.
AT_2	ECR Austria – Efficient Consumer Response & ABF-BOKU	2013	Lebersorger S, Schneider F (2014b) Aufkommen an Lebensmittelverderb im österreichischen Lebensmittelhandel. Endbericht im Auftrag der ECR-Arbeitsgruppe Abfallwirtschaft 2014.
BE_1	Flemish Food Supply Chain Platform for Food Loss	2015	Flemish Food Supply Chain Platform for Food Loss. (2017). Food waste and food losses: prevention and valorisation, Monitoring Flanders 2015. Vlaams Ketenplatform Voedselverlies.
BE_2	Department of Agriculture and Fisheries of the Government of Flanders	2016	Roels, K., & van Gijseghem, D. (2017). The Impact of Cosmetic Quality Standards on Food Losses in the Flemish Fruit and Vegetable Sector: Summary Report. Department of Agriculture and Fisheries, Brussels.
BE_3	Flemish Food Supply Chain Platform for Food Loss	2016-2018	Flemish Food Supply Chain Platform for Food Loss. (2018). Food Loss and Consumer Behaviour in Flemish Households. Summary of the report: GfK (2018b). Voedselverlies en consumentengedrag bij Vlaamse huishoudens, studie in opdracht van het Departement Omgeving.
CZ_1	Strefowa Project	Based on 2013 and 2010	Gruber, I., Hrad, M., Mayerhofer, J., Obersteiner, G., Schmied, E., Maritz, C., Pattermann, H. (2016). Report on Status Quo of Food Waste Prevention and Management.
DE_1	Corsus-corporate sustainability	2010	Eberle, U., & Fels, J. (2016). Environmental impacts of German food consumption and food losses. The International Journal of Life Cycle Assessment, 21(5), pp. 759-772.
DE_2	Universität Stuttgart & Universität für Bodenkultur Wien (BOKU)	Manufacturing: not mentioned. Retail: based on 2011. Consumption: not mentioned	Kranert, M., Hafner, G., Barabosz, J., Schneider, F., Lebersorger, S., Scherhaufer, S., Schuller, H., Leverenz, D., 2012. Determination of discarded food and proposals for a minimization of food wastage in Germany. Institute for Sanitary Engineering, Water Quality and Solid Waste Management University Stuttgart.
DK_1	Technical University of Denmark and Econet	2011/2012	Edjabou, M. E., Petersen, C., Scheutz, C., Astrup, T. F. (2016). Food waste from Danish households: Generation and composition. Waste Management, 52, pp. 256-268

[4] TESCO (2019). Central Europe Food Waste Data 2017/2018. Available at: https://sustainability.tescoplc.com/sustainability/food-waste/topics/central-european-food-waste-data-201718/

Code	Entity developing the study	Year/s of measurement	Reference
DK_2	Ministry of Environment and Food	Manufacturing: Based on 2011, 2013 and 2016 Distribution: Based on 2014 and 2016 Food Services: based on 2002, 2004, 2011, 2012, 2013, 2014, 2015. Households: 2014 and 2015	Tonini, D., Brogaard, L. K.-S., & Astrup, T.F. (2017). Food waste prevention in Denmark. Identification of hotspots and potentials with Life Cycle Assessment. Danish Environmental Protection Agency, Copenhagen.
DK_3	Norden	2010-2013	Franke, U., Hartikainen, H., Mogensen, L., Svanes, E. (2016) Food losses and waste in primary production. Data collection in the Nordic countries.
EE_1	Stockholm Environment Institute	2014	Moora, H., Urbel-Piirsalu, E., & Õunapuu, K. (2015). Toidujäätmete ja toidukao teke Eesti kodumajapidamistes. SEI Tallinna uuringu aruanne. Stockholm Environment Institute, Project Report 2015-08.
EE_2	Estonian University of Life Sciences, Economic and Social Institute	2018	Värnik, R., Lillemets, J., & Aro, K. (2018). Toidujäätmete ja toidukadude teke Eesti põllumajanduses ja kalanduses. Estonian University of Life Sciences, Economic and Social Institute
EE_3	Stockholm environment institute	2015	Moora, H., Urbel-Piirsalu, E., & Viilvere, T. (2015). Toidujäätmete teke Eesti kaubandus- ja toiduainetööstusettevõtetes. Stockholm Environment Institute
EL_1	Harokopio University	Prior to the consumption phase = 2009. Households = 2013	Abeliotis, K., Lasaridi, K., Costarelli, V., & Chroni, C. (2015). The implications of food waste generation on climate change: The case of Greece. Sustainable Production and Consumption, 3, pp. 8-14.
ES_1	Ministry of Environment of Spain	Production and Manufacturing - Report published in 2014 but the year of measurement is not mentioned. Distribution: report requested. Consumption: 1. Canteens from the Public Administration: 2015 2. Schools. Report published in 2016 but the year of measurement is not mentioned. 3. Households. (2015-2016)	Ministerio de Agricultura, Pesca y Alimentación (2018). Spanish Strategy "More food, less waste". Publications Catalogue of the Spanish National Government.
ES_2	Ministry of Environment of Spain	2018	Ministry of Environment of Spain. (2018). Informes Desperdicios Primavera Verano 2018.
FI_1	MTT Agrifood Research,	2010	Silvennoinen, K., Katajajuuri, J., Hartikainen, H. (2014). Food waste volume and composition in Finnish households British Food Journal 116 (6), pp. 1058-1068
FI_2	MTT Agrifood Research	2010-2012	Silvennoinen, K., Katajajuuri, J.M., Hartikainen, H., Jalkanen, L., Koivupuro, H.K. Reinikainen, A. (Food waste volume and Composition in the finnish supply Chain: special focus on food service sector Proceedings Venice 2012, Fourth International Symposium on Energy from Biomass and Waste Cini Foundation, Venice, Italy; 12 - 15 November 2012

Code	Entity developing the study	Year/s of measurement	Reference
FI_3	MTT Agrifood Research Finland	2010	Katajajuuri, J. M., Silvennoinen, K., Hartikainen, H., Heikkilä, L., & Reinikainen, A. (2014). Food waste in the Finnish food chain. Journal of Cleaner Production. 73, pp/322-329
FI_4	Same as DK_3		
FR_1	ADEME	2015-2016	Vernier, A., Debarge, S., Galio, P., Martin, S., Colomb, V. (2016). Food losses and waste - inventory and management at each stage in the food chain. Executive summary. Study realized on behalf of the French Environment and Energy Management Agency (ADEME) by INCOME consulting – AK2C.
HR_1	Hrvatska agencija za okoliš i prirodu	2017	Golubovac, N. (2018). Unaprjeđenje sustava za prikupljanje podataka o biootpadu i otpadu od hrane. Hrvatska agencija za okoliš i prirodu.
HU_1	Agricultural Team of the Embassy of the Kingdom of the Netherlands in Budapest	(_)	Bori, P. (2018). The state of food waste in Hungary. A report by the Agricultural Team of the Embassy of the Kingdom of the Netherlands in Budapest, Hungary.
HU_2	Directorate for Food Safety Risk Assessment (DFSRA), National Food Chain Safety Office	2016	Szabó-Bódi, B., Kasza, G., & Szakos, D. (2018). Assessment of household food waste in Hungary. British Food Journal, 120(3), 625–638.
IE_1	TESCO	Financial year 2017/18 (February 2017-February 2018)	TESCO (2019). Ireland Food Waste Data 2017/2018.
IT_1	Barilla Center for Food & Nutrition	Total: 2005-2006 Production: 2009 Manufacturing: Not provided Consumption: 2008-2010	Buchner, B., Fischler, C., Gustafson, E., Reilly, J., Riccardi, G., Ricordi, C., & Veronesi, U. (2012). Food waste: causes, impacts and proposals. Barilla Center for Food & Nutrition
LU_1	Eco-Conseil	Manufacturing: not mentioned Retail: not mentioned Consumption out of home: 2012-2013 Households: 2000-2014	Beyer, H.J., & Winter, G. (2016). Aufkommen, Behandlung und Vermeidung von Lebensmittelabfällen im Großherzogtum Luxemburg. Eco-Conseil.
LV_1	Latvia University of Agriculture	2013	Tokareva, T., & Eglite, A. (2017). Food waste in Latvian housholds: amounts, economic aspects. In: Econommic Science for Rural Development Conference Proceedings (46), 213–219.
LV_2	Latvia University of Agriculture	2013 and 2016	Tokareva, T. (2017). Latvian households' food wasting in the context of eating habits. PhD thesis.
MT_1	National Statistics Office	2011-2012	National Statistics Office Malta. (2012) Household Waste Composition Survey: 2012.
MT_2	Ministry for Sustainable Development, the Environment and Climate Change	2002, 2012 and 2013	Ministry for Sustainable Development, the Environment and Climate Change (2014). Waste Management Plan for the Maltese Islands: A Resource Management Approach 2014-2020.
NL_1	Wageningen UR Food & Biobased Research	2009-2011	Soethoudt, H., & Timmermans, T. (2013). Monitor Voedselverspilling. Mid-term rapportage. Report 1372. Wageningen UR Food & Biobased Research.
NL_2	Wageningen UR Food & Biobased Research	2009-2016	Soethoudt, H., & Vollebregt, M. (2016). Monitor Voedselverspilling. Update 2009-2016. Wageningen UR Food & Biobased Research.
NL_3	Voedingscentrum	2016	Kaal, M., Hooijmans, S., & Houtepen, I. (2017). Voedselverspilling in Nederland op basis van

Code	Entity developing the study	Year/s of measurement	Reference
			zelfrapportage. Stichting Voedingscentrum Nederland, Den Haag.
NL_4	Voedingscentrum	2009, 2010, 2012, 2013, 2016	Van Dooren, C. (2017). Oplegnotitie Voedselverspilling bij huishoudens in Nederland in 2016. Stichting Voedingscentrum Nederland, Den Haag.
NL_5	Wageningen Food & Biobased Research	Not provided	Tromp, S.O., 2018. Derving in de supermarkt kan flink omlaag: Deel 2: onderzoek en maatregelen voedselverspilling in de biologische keten. Ekoland, (6), pp.32-33.
NO_1	Matvett AS (Østfoldforskning)	2010-2016	Stensgård, A. E., & Hanssen, O. J. (2018). Food Waste in Norway: Report on Key Figures. Matvett AS.
NO_2	Avfall Norge	2015-2017	Syversen, F., Hanssen, O. J., & Bratland, H. (2018). Nasjonal beregning av mengde matsvinn på forbrukerleddet. Avfall Norge
NO_3	Same as DK_3		
PL_1	Warsaw University of Life Sciences	2016	Bilska, B., Piecek, M., & Kołozyn-Krajewska, D. (2018). A multifaceted evaluation of food waste in a Polish supermarket-Casestudy. Sustainability, 10(9), p. 3175. https://doi.org/10.3390/su10093175
PT_1	Fundação Calouste Gulbenkian	2011-2012	Baptista, P., Campos, I., Pires, I., & Vaz, S. (2012). Do campo ao garfo. Desperdicio alimentar em Portugal. Lisboa: CESTRAS.
PT_2	Instituto Politecnico de Coimbra and University of Aveiro	2014	Dias-Ferreira, C., Santos, T., & Oliveira, V. (2015). Hospital food waste and environmental and economic indicators - A Portuguese case study. Waste Management, 46.
RO_1	University of Agronomic Sciences and Veterinary Medicine of Bucharest and National Research and Development Institute for Food Bioresources-IBA Bucharest	2016	Iorga, S. C., Apostol, L., Belc, N., Mosoiu, C. E., Berca, L. M., Niculae, O. M., & Popa, M. E. (2017). Profile of high risk wasting food consumer in Romania. Scientific Bulletin. Series F. Biotechnologies, 21, pp.301-307.
SE_1	Swedish Environmental Research Institute	2014 and 2016	Jensen, C., Hultén, J., & Viklund, L. (2017). Uppföljning av etappmålet för ökad resurshushållning i livsmedelskedjan - data för år 2016. Sveriges Meteorologiska och Hydrologiska Institut.
SE_2	Same as DK_3		
SI_1	Republica of Slovenia. Statistical Office	2013-2017	Republica of Slovenia. Statistical Office. Food Waste Generation in Slovenia. Years 2013-2017.
SI_2	Republica of Slovenia. Statistical Office	2013-2015	Vidic, T., & Žitnik, M. (2017). Food Waste Generation And Treatment in Slovenia. Republica of Slovenia Statistical Office.
UK_1	WRAP	2015	WRAP (2018). Courtauld Commitment 2025 – food waste baseline for 2015
UK_2	TESCO	Financial year 2017/18 (February 2017-February 2018)	TESCO (2019). UK Food Waste Data 2017/2018.

3.1 Food waste definition

Several definitions of food waste were used across the studies analysed as illustrated in Table 3. 7 studies did not state explicitly what was the definition of food waste adopted, while 27 (Table 4) used their own definition of food waste (i.e. not referring explicitly to any definitional framework such as FAO or FUSIONS). Some of the studies follow terms and definitions used in previous studies (mentioned in section 2):

- Monier et al. (2010) definition was used in 2 studies. In Monier et al. (2010) food waste is defined as part of bio-waste[5], composed of raw or cooked food materials. It includes food materials discarded at any time between farm and fork; in households relating to food waste generated before, during other food preparation, e.g. vegetables peelings, meat trimmings, spoiled or excess ingredients or prepared food.
- FAO (2011) definition was used in 5 studies. FAO discriminates between food losses and food waste. Food loss is the decrease in food quantity or quality in the early stages of the food supply chain, reducing the amount of food suitable for human consumption. Often related to post-harvest activities with lacking system or infrastructural capacities. Food waste is, instead, related to the discarding of food products that are fit for consumption or fit to proceed in the FSC. Food waste mostly occurs at the later stages of the FSC, such as retail and consumer households.
- FUSIONS (2016b) definition was used in 6 studies. Here, food waste is defined as fractions of food and inedible parts of food removed from the food supply chain to be recovered or disposed (including composted crops, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).

The FLW Standard does not provide a definition for food waste. It requires users to account for two components: material type and destination. Material type refers to the material that is removed from the FSC (i.e. food and/or associated inedible parts) and quantified in a food losses and waste inventory. Depending on the goals of the quantification, an entity may account for: only food removed from the FSC, only associated inedible parts, or both food and associated inedible parts. Destination refers to where the material removed from the FSC is directed (10 possible destinations are considered). The FLW Standard does not specify precisely which set of destinations comprises 'loss and waste' and leaves it up to the user to decide what makes up the particular definition of 'food loss' or 'food waste' on which they report, based on their quantification goals (FLW Protocol, 2016). The studies conducted by TESCO (IE_1, UK_2, and CE_1) referred to the FLW Standard, stating that the data provided is in conformance with the standard. These studies used the FUSIONS food waste definitions. Also study UK_1 was conducted following the FLW standard requirements and, although not stated specifically, the definition of food waste adopted in the study is in line with the FUSIONS definition.

Additional definitions used in the studies are presented in Table 4. As several of the studies analysed were published in the language of the MS, in those cases the definition of food waste provided was translated by the authors of this work. This table shows as well if the study accounts for edible and/or inedible parts of food, providing combined or separate figures. It also reports whether the concepts of avoidable/unavoidable food waste were used, proving or not separate figures ('Differentiated' or 'Not differentiated'), or not used ('Not mentioned'). Overall, there is a consistent use of the terms 'edible' and 'inedible', where the second refers to all the parts of food items that cannot be / are not usually eaten (e.g. bones, peels). Conversely, there seems to be more heterogeneity on the interpretation of 'avoidable' and 'unavoidable' food waste, with some studies using also the

[5] Bio-waste: biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge or other biodegradable waste (e.g. natural textile, paper or processed wood)

term "possibly avoidable" for those items that are eaten by some and discarded by others (e.g. apple peel).

The definition of food waste adopted in BE_3, EE_2, FI_1, FI_2, FR_1, NL_1, NL_2, NO_1 and NO_2 are quite similar to the FAO definition as they refer to edible parts of food intended for human consumption that were not used for this purpose.

Table 3. Number of reports and countries using additional definitions, or from previous studies (FAO 2011, FUSIONS 2016, and Monier et al., 2010), or not providing a definition at all.

Food waste definition source	Studies
Monier et al. (2010)	EL_1, SI_1
FAO (2011)	FI_3, IT_1, NL_4, PL_1, PT_1
FUSIONS (2016b)	DK_1, DK_2, DK_3, FI_4, IE_1, NO_3, SE_2, UK_1, CE_1
Own definition	see table 4
Not provided	HR_1, LU_1, MT_1, MT_2, NL_5, RO_1, SE_1

* Tesco case study covering Czech Republic, Hungary, Poland and Slovakia

DK_1 used the FUSIONS definitions and analysed the share of avoidable and unavoidable food waste considering 6 detailed fractions: (1) avoidable unprocessed vegetable food waste, (2) avoidable processed vegetable food waste, (3) unavoidable vegetable food waste, (4) avoidable unprocessed animal-derived food waste, (5) avoidable processed animal-derived food waste, and (6) unavoidable animal-derived food waste.

For the case of BE_1, 'food loss' refers to 'food commodity or a product designated for human food consumption that is ultimately not consumed by people'. Instead, 'food waste' refers to the 'edible fraction of food commodities or products (in the form of food loss) or the inedible fraction of food commodities or products (in the form of residues) that disappear from the agri-food chain aimed at human food (i.e. they are given a non-human destination)'. In the other studies analysed for Flanders, BE_2 and BE_3 (both more recent than BE_1), only the term food losses was used. In BE_2, it refers to food products that were eventually not used for human consumption and were applied back in the land, used as animal feed, composted, anaerobic digested or simply not harvested. In BE_3, it refers to edible food and drink fractions from products or meals that were acquired with the intention to be consumed by humans but were instead discarded.

Other studies that only used the term 'food loss/losses' are studies DE_1 and EE_2. In the former, food losses were defined as the parts of a food product that are not eaten, including raw products (i.e. those that are not harvested) as well as losses in food processing or food waste in households. In the latter, this term refers to unprocessed or processed food that was originally intended for human consumption, but for one reason or another, was not consumed. Other study for Germany (DE_2) uses instead, the term 'food waste' referring to food residues from agricultural production, processing of food, wholesale and retail, kitchens of large consumers, private households.

This diversity of food waste-related terms and definitions has been already highlighted by Roodhuyzen et al. (2017) and Caldeira et al. (2017) who reported a clear lack of consensus on terminology and definitions across food waste accounting studies. According to the authors, the definitions used can focus on different elements, including: physical/nutritional aspects (e.g. inclusion of edible and non-edible food), the stage(s) of the FSC where the food waste is generated; 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.

Table 4. Additional definitions used in the studies.

Study code	Food waste definition	Edible / Inedible*	Avoidable/ Unavoidable**
AT_1	**Food waste:** all food and drinks wasted in kitchen operations (including storage and preparation losses) and at consumption (unserved food, buffet remains and plate leftovers).	Edible + Inedible (separate figures)	Differentiated
AT_2	**Food losses** (at retail stage): unsold food products and products returned to suppliers.	Edible + Inedible (combined)	Not differentiated
BE_1	**Food loss:** food commodity or a product designated for human food consumption that is ultimately not consumed by people **Food waste**: edible fraction of food commodities or products (in the form of food loss) or the inedible fraction of food commodities or products (in the form of residues) that disappear from the agri-food chain aimed at human food (i.e. they are given a non-human destination). Waste flows released during primary production before the crops are ready for harvest or the animals are ready for slaughter are not part of the agri-food chain and therefore fall outside the definition of 'food waste'.	Edible + Inedible (separate figures)	Not differentiated
BE_2	**Food losses**: food products that eventually are not used for human consumption and are applied back to land, used as animal feed, composted, anaerobic digested or simply not harvested.	Edible + Inedible (combined figures)	Not differentiated
BE_3	**Food loss:** edible food and drink fractions from products or meals that are acquired with the intention to be consumed by humans but remain unconsumed and are discarded.	Edible	Not mentioned
CZ_1	**Food waste (including food loss):** refers to food as well as associated inedible parts removed from the food supply chain. That means they are not used for normal human consumption.	Edible + Inedible (combined figures)	Not differentiated
DE_1	**Food losses**: parts of a food product that are not eaten, including raw products (i.e., those that are not harvested) as well as losses in food processing or food waste in households.	Edible + Inedible (combined figures)	Not differentiated
DE_2	**Food waste**: food residues from agricultural production, processing of food, wholesale and retail, kitchens of large consumers, private households. Raw and processed food fit for human consumption.	Edible + Inedible (combined figures)	Differentiated
EE_1	**Food lost or wasted**: food originally intended for human consumption, which, for whatever reason, is not consumed by humans (e.g. spoiled, overdue, improper storage and handling).	Edible + Inedible (separate figures)	Differentiated
EE_2	**Food loss**: unprocessed or processed food that was originally intended for human consumption, but for one reason or another, it was not consumed (e.g. composted, used for on bioenergy production, as animal feed).	Edible	Not mentioned
EE_3	**Food waste**: food (including inedible parts) leaving the FSC, excluding food used as material (e.g. for the production of bio-based products and animal feed), or redistributed (e.g. food donation). **Food loss**: any food or food product originally intended for human consumption which has been removed from the FSC for economic or aesthetic reasons, or because of the overrun of the consumption period, but which is still edible and fit for human consumption.	Edible + inedible (combined figures)	Not mentioned

Study code	Food waste definition	Edible / Inedible*	Avoidable/ Unavoidable**
ES_1 & ES_2	**Food waste:** food discarded due to human error caused by shopping and consumption habits, incorrect storage or preparation of food (differentiating between food discarded unconsumed and food discarded after preparation).	Not mentioned	Avoidable
FI_1 & FI_2	**Food waste:** all wasted food and raw materials that could have been eaten if they had been stored or prepared differently.	Edible	Differentiated
FR_1	**Food waste:** all food intended for human consumption that, at one stage of the food chain, is lost, thrown away or degraded.	Edible (Edible & potentially edible)	Avoidable
HU_1	**Food waste:** food not intended for human consumption, or food intended but unfit for human consumption, including food remains from the HoReCa industries, foods that have passed their gone-by-date, foods that were damaged during packaging and pose a threat to food safety, polluted unpackaged foods, waste as a by-product of food cleaning, used cooking oils.	Edible + inedible (combined figures)	Not mentioned
HU_2	**Household food waste:** avoidable and unavoidable (non-consumable animal and plant parts) food waste generated by households that is either discarded, home-composted or fed to pets.	Edible + Inedible	Differentiated
LV_1	**Food waste:** food discarding, whose expiration date has expired, or food discarding, whose taste, look, smell has changed and is no longer suitable for consumption.	Not mentioned	Not differentiated
LV_2	**Waste of food at household level:** food valid for consumption that is discarded fully or partly.	Not mentioned	Not differentiated
NL_1 & NL_2	**Food waste:** food intended for human consumption that is not used for this. Food that was not intended for human consumption does not fall within the definition and is therefore not included in the quantification of food waste.	Edible	Avoidable
NL_3	Self-reported waste of solid food, liquid food and dairy (excluding inedible parts).	Edible	Not differentiated
NO_1 & NO_2	**Food waste:** all useful parts of food produced for humans which are either discarded or removed from the food chain for other purposes than human food, from the time of slaughter or harvesting.	Edible	Avoidable
PT_2	**Plate waste:** food served but not eaten, referring both to food tried by patients but incompletely consumed as well as to untouched food.	Edible + Inedible (combined figures)	Not differentiated
SI_2	**Food waste:** includes raw or processed food and remains of this food lost before, during or after food preparation or during food consumption, including food discarded during production, distribution, sale and implementation of food-related services and in households.	Edible + Inedible (separate figures)	Not mentioned

* information about the accounting for edible or inedible parts of food or for both, providing combined or separate figures

** information about the use of the concepts avoidable/unavoidable, with or without proving separate figures ('Differentiated' or 'Not differentiated'), or not used ('Not mentioned')

3.2 Scope and system boundaries

This section presents the scope and boundaries of the studies, which includes: (i) the identification of the stages of the FSC covered (primary production, processing and manufacturing, retail and other distribution of food, restaurants and food services, and households), (ii) the temporal and the geographic scope, and (iii) which were the food commodities analysed.

3.2.1 Stages of the food supply chain covered

Figure 1 depicts the number of studies covering each stage of the FSC. Households were the stage mostly covered by the studies analysed, with 35 studies, followed by the retail and distribution with 27 studies. Then, there are 21 studies covering restaurants and food services, 19 covering the processing and manufacturing stage, and 19 studies focusing on food waste at primary production.

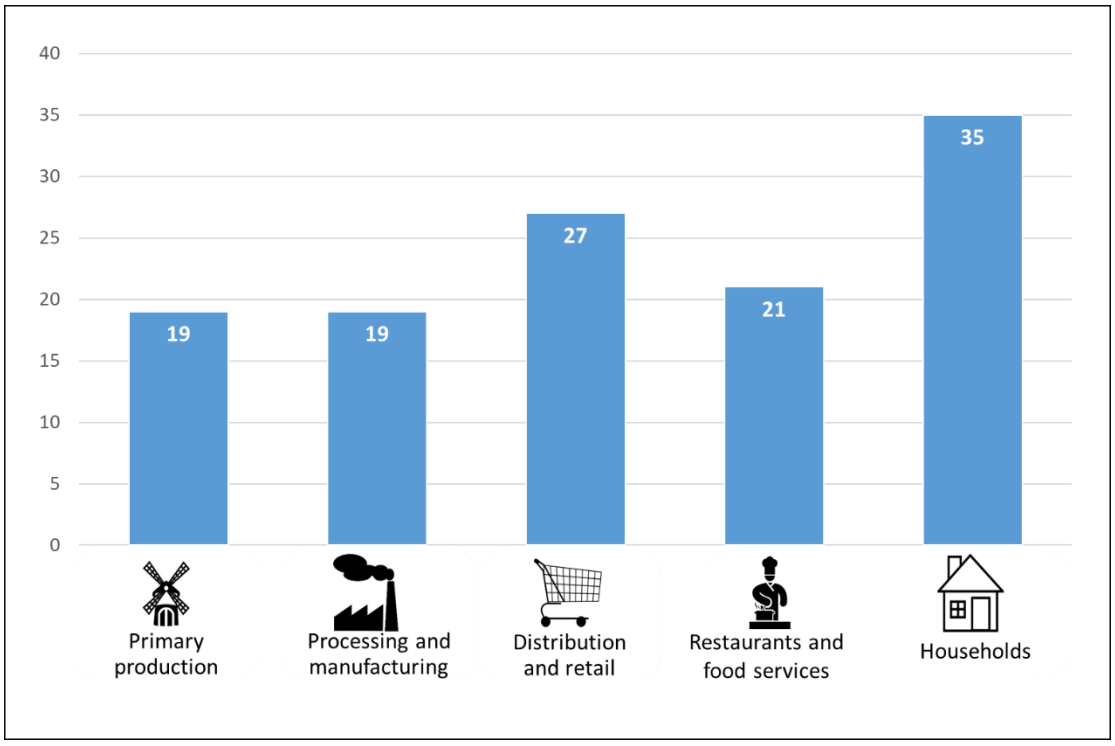
It is important to highlight that there are studies that have assessed specific stages, without providing numerical results in terms of amounts of food waste generated. For example for primary production, although 19 of the studies analysed included this stage in their system boundaries, only 14 provided data. These cases are distinguished in Table 5, which shows the stage of the FSC covered in each study for which food waste amounts were provided (identified with an 'X'), and those stages that were covered but for which no results were provided (identified with 'ND'). In these cases, studies reported results up-scaled to national level.

The studies that do not report data at national level (referred in this report as case studies) are also identified in the table. These include:

(i) studies only covering one region of the country (identified with 'R'),
(ii) case studies focusing on a small sample for example, only a supermarket (identified with 'CS').

The food waste definition used in each study is also reported in Table 5.

Figure 1. Number of studies covering each stage of the food supply chain*.



*the figures refer to stages covered independently if the amounts of food waste were provided or not.

Table 5. Stages of the FSC covered in each study and the food waste definition used.

Code	Primary Production	Processing & Manufacturing	Retail & Distribution	Restaurants and Food service	Households	Food waste definition
AT_1				X		OD
AT_2			X			OD
BE_1	R	R	R	R	R	OD
BE_2	R					OD
BE_3					R	OD
CZ_1	X	X	X	X	X	F
DE_1	ND	ND	ND	X	X	OD
DE_2		X	X	X	X	OD
DK_1					X	F
DK_2	X	X	X	X	X	F
DK_3	X					F
EE_1				X	X	OD
EE_2	ND					OD
EE_3		X	X			OD
EL_1					X	M
ES_1	ND	ND	ND	ND	X	OD
ES_2					X	OD
FI_1					X	OD
FI_2				X		OD
FI_3		X	X	X	X	FAO
FI_4	X					F
FR_1	X	X	X	X	X	OD
HR_1	X	X	X	X	X	NP
HU_1		X	X	X	X	OD
HU_2					X	OD
IE_1			CS			F
IT_1	X	X	X		ND	FAO
LU_1		ND	X	X	X	NP
LV_1					ND	OD
LV_2					X	OD
MT_1					X	NP
MT_2					X	NP
NL_1	ND	ND	ND	ND	X	OD
NL_2	ND	ND	ND	ND	ND	OD
NL_3					X	OD
NL_4					X	FAO
NL_5			CS			NP
NO_1		X	X		ND	OD
NO_2					X	OD
NO_3	X					F
PL_1			CS			FAO
PT_1	X	X	X	X	X	FAO
PT_2				CS		OD
RO_1					X	NP
SE_1			X	X	X	NP
SE_2	X					F
SI_1	X	X	X	X	X	M
SI_2	X	X	X	X	X	OD
UK_1		X	X	X	X	F
UK_2			CS			F
CE_1			CS			F

X: food waste reported at national level; ND: stage covered but no data on food waste provided; R: food waste reported at regional level; CS: food waste reported for a small sample; *not upscaled to national level
NP: Not provided; OD: Own definition; F: from FUSIONS (2016); FAO: from FAO (2011); M: from Monier et al. (2010)

As shown in Table 5, there are relatively few examples of countries for which the studies analysed covered the entire FSC. For some countries, the entire FSC is covered by combining the results of several studies, however different definitions might have been used and therefore comparability is not straightforward.

For some countries, the studies gathered covered only one stage of the FSC. This is the case for Latvia and Malta for which the studies covered only households, and for Poland and Ireland, conducting case studies at the retail and distribution stage. Countries for which no study conducted at national level was found are Belgium, Bulgaria, Cyprus, Ireland, Poland, and Lithuania.

3.2.2 Temporal and geographic scope

The studies collected refer to food waste quantified in the different EU countries over different years and at different geographical scales: national level, regional level, and case studies. Table 2 provides information on the measurement year(s) for each study as well as an indication on whether the study was carried out at national level, regional level or as a case study.

Within the studies reporting data at national level three groups of studies can be identified:

1) studies that report data for one single year. In this case, the years mostly covered are from 2013 to 2018;

2) studies reporting results based on data from different years for different stages of the FSC. This is the case, for example of DK_2, in which the amounts of food waste reported at processing and manufacturing are based on data from 2011, 2013 and 2016; those for retail and distribution are based on data from 2014 and 2016; those for food services are based on data from 2002, 2004, 2011, 2012, 2013, 2014, 2015, and for households based on data from 2014 and 2015;

3) studies reporting data for different years, this is the case of NO_1 that reports data on food waste generated at processing and manufacturing and at retail and distribution from 2010 to 2016.

Three regional studies were included in the review, these were conducted for the region of Flanders in Belgium in the years 2015 (BE_1), 2016 (BE_2), and 2016-2018 (BE_3).

The case studies considered were:

- NL_5 refers to the analysis of the products with the highest loss rate in a supermarket, based on the comparison between losses and sales of different products.
- PL_1 focused on the food waste generated in a supermarket, analysing a total of 1,245 food products in two weeks in 2016. Additionally, it presents an estimation of the annual generation of food waste for this supermarket and of its monetary value.
- PT_2 quantified food waste generated in one hospital in 2014. Additionally, it also analysed actions to prevent food waste in hospitals, measuring the degree of ease of implementation and the estimation of the percentage of food waste avoided thanks to these measures. Moreover, an analysis of the impact of these measures (economic and environmental) was included.
- The studies by Tesco, IE_1, UK_2 and CE_1, are case studies referring to food waste generated by the activities of this company in Ireland, UK, and Central Europe (Czech Republic, Hungary, Poland and Slovakia.) They refer to Tesco financial year 2017/18 (from 26th February 2017 to 24th February 2018). Food waste arising from Tesco' depots and stores in the countries considered, excluding food waste arising in customer restaurants and staff canteens of the stores and depots, was quantified. Food waste arising in the operations owned by Tesco, upstream in the supply chain, such as haulage wastage and committed crop wastage was not included. The estimation only covers Tesco's operations, excluding waste arising theirs suppliers' sites and from third party counters in Tesco stores.

Only two studies refer explicitly to the assessment of food waste associated with (i.e. embedded in) trade: DK_2 and ES_1. In both cases, food waste associated with trade

was not considered. DK_2 states that the food waste associated with the production of the imported food and with the commercialization and use of the exported food were excluded from the assessment because the geographic scope of the study is Denmark. ES_1 excludes exported products from the scope of the study.

3.2.3 Food commodity groups

Figure 2 presents an overview of the breakdown into food commodity groups reported by each study. Of the 48 studies analysed, 19 reported the total food waste without differentiating between food commodity groups, while 15 studies reported food waste amounts for more than 10 food commodity groups. As illustrated by Figure 3, product groups mostly included are vegetables, fruit, meat, and dairy.

Figure 2. Number of studies providing results for different food commodity groups.

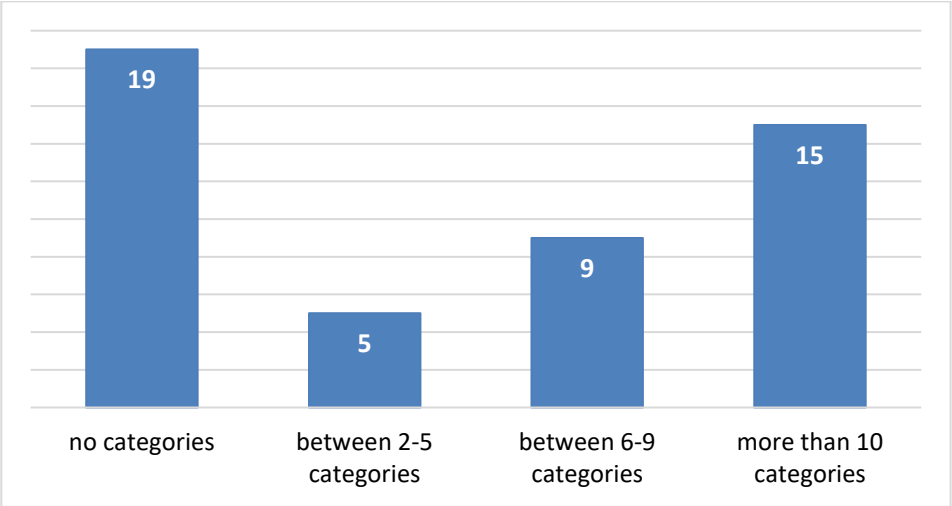
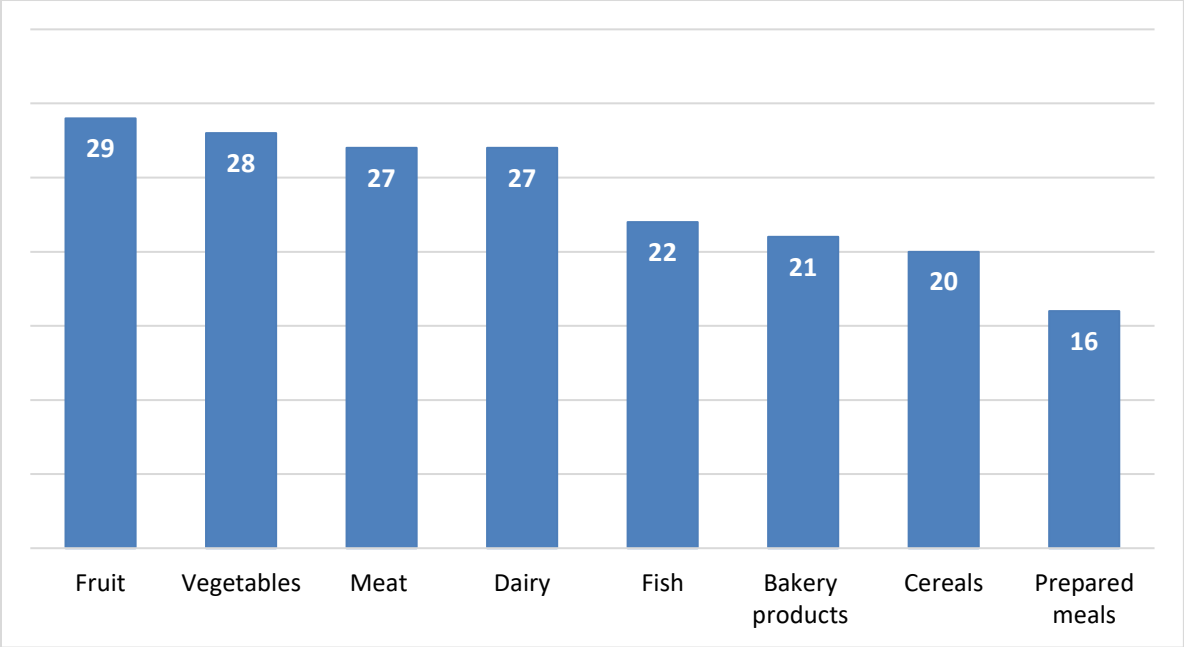


Figure 3. Number of studies providing food waste amount for a selection of food commodity groups.



3.3 Accounting methodology

As mentioned in section 2.2, several measurement methods (box 1) can be used to quantify food waste. In this section, an overview of the different measurement methods used in the studies is presented.

Figure 4 depicts the number of studies that used each quantification method and Figure 5 shows how many studies used each quantification method at each stage of the FSC. Detailed information on the quantification methods used in each study, by stage of the FSC, is presented in Table 6.

Among the direct methods – weighing, waste composition analysis, surveys, diaries, records, and observation – the one most used was surveys. Such method was used at different stages of the FSC, depending on the study, but mostly to quantify food waste generated by households. A study recently published (van Herpen et al, 2019) has compared 5 different methods used to measure food waste at household level: survey questions about general food waste over a non-specified period of time, diaries, photo coding, kitchen caddies, and pre-announced survey questions regarding a specific time period. According to the results, the general survey questions appear to be less valid, leading to a large underestimation of the level of food waste. It was also reported that this method provides low variance in reported food waste across households compared to the other methods, and low correlations with other measures, while the other four methods resulted relatively highly correlated. To take into account the possible underestimation provided by surveys and diaries, FI_3 provided two different numbers for the food waste generated by households. One figure refers to the amount of food waste generated estimated based on the surveys and diaries, and the second one is a higher estimation assuming that: (i) there were fewer single-person households in the sample than there are in average in Finland (these single households produced more food waste per person on average), and (ii) some participants might have changed their normal behaviour patterns during the study period, producing less waste than what they do on average.

Waste composition analyses and diaries were only used at the consumption stage, for restaurants and food services, and for households. Observation was used only in one study, conducted in school canteens (ES_1).

Among the indirect methods – modelling, mass balance, proxy, and literature data – proxy data and literature data were the methods mostly used, being applied at all the stages of the FSC. None of the studies used modelling to account for food waste.

As shown in Table 6, several studies have used a combination of methods to quantify food waste, combining direct with indirect methods. For example, BE_1 used a combination of weighting, records and literature data to determine food waste at primary production. Additionally, it used waste composition analyses and literature data to account for household food waste, and proxy data for manufacturing, retail, and restaurants and food services. Some of the studies were done using exclusively literature data: CZ_1, DE_1, DK_2, HU_1, and IT_1.

Figure 4. Number of studies that used the different measurement methods.

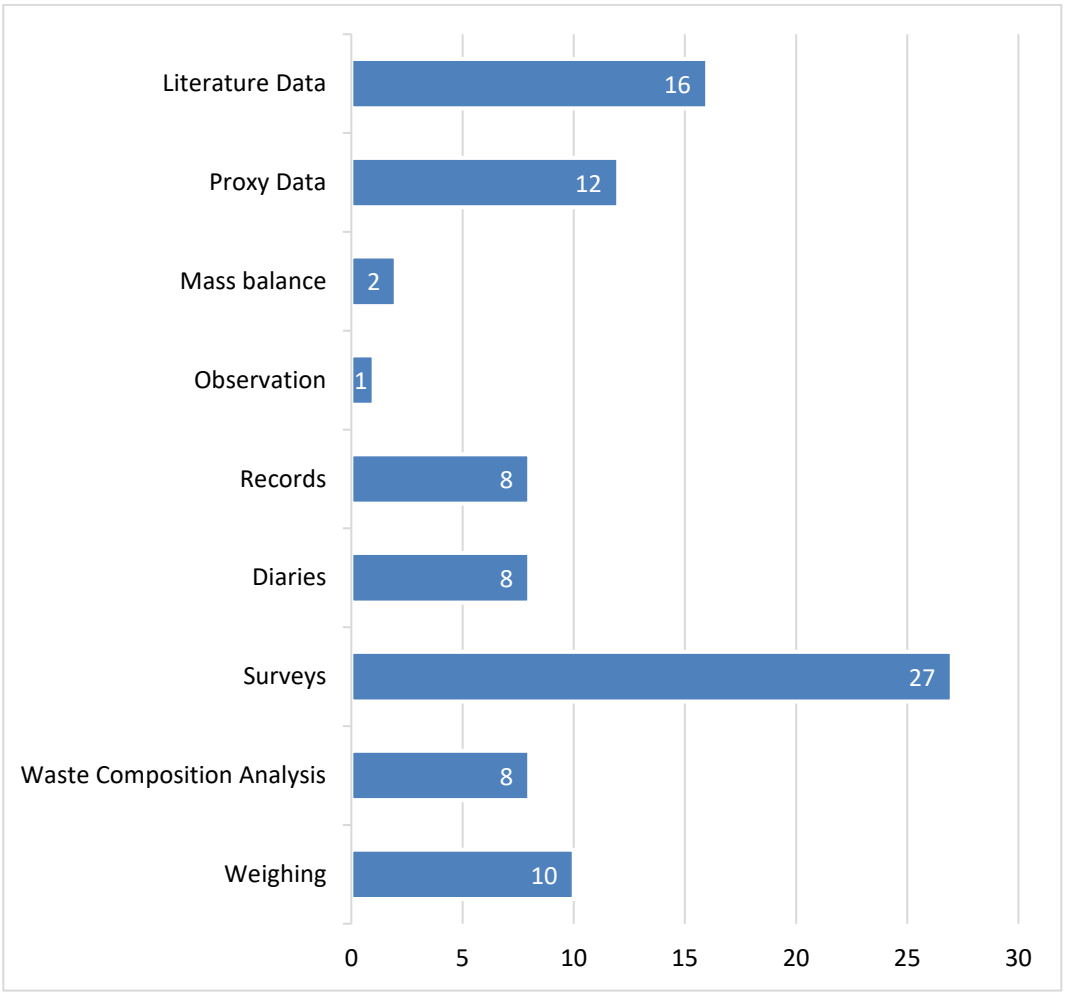


Figure 5. Food waste quantification methods used by the studies analysed for each stage of the FSC.

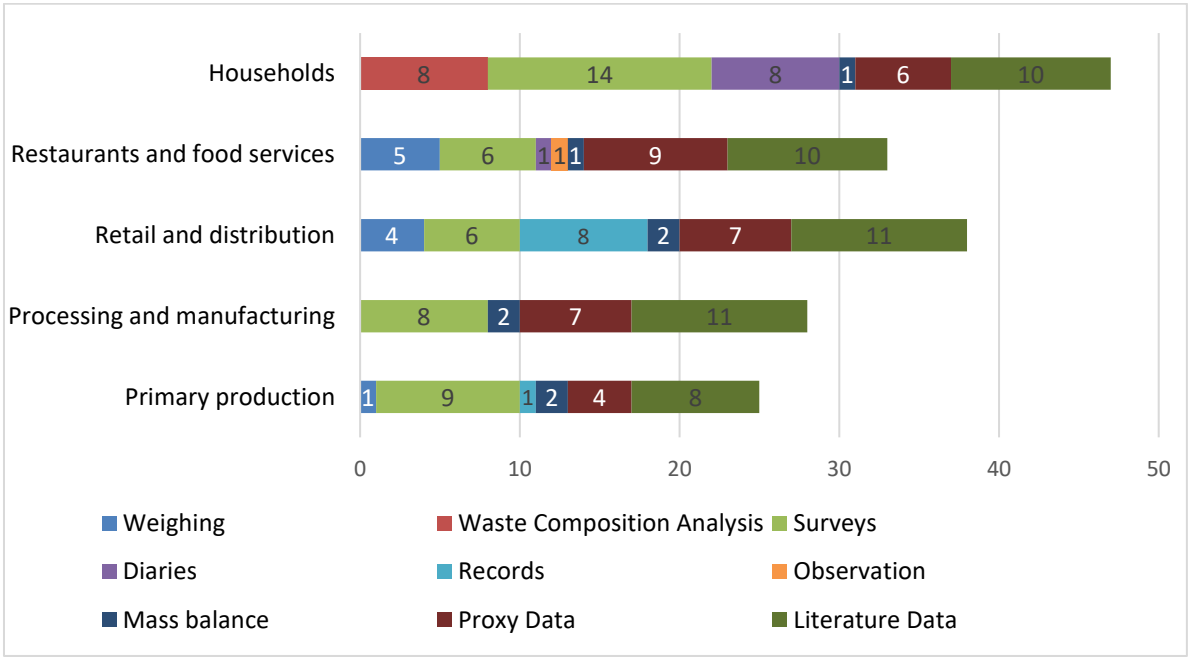


Table 6. Quantification methods used in each study in each stage of the FSC. PP: Primary Production; RD: Retail and Distribution; RFS: Restaurants and Food service

Study code	Direct methods						Indirect methods		
	Weighing	**Waste Composition Analysis**	**Surveys**	**Diaries**	**Records**	**Observation**	**Mass balance**	**Proxy Data**	**Literature Data**
AT_1	RFS								
AT_2					RD				
BE 1	PP (Auctions)	Households	Manufacturing RD		PP (Fisheries) RD			RFS	PP (Fisheries and agricultural production); Households
BE_2			PP						
BE_3			Households	Households					
CZ 1									All chain
DE 1									All chain
DE_2		Households	Manufacturing					RFS	RD
DK_1		Households							
DK 2									All chain
DK_3			PP						
EE_1	RFS		Households	Households					
EE_2			PP						
EE_3			Manufacturing RD					Manufacturing RD	Manufacturing RD
EL_1				Households					

Study code	Direct methods						Indirect methods		
	Weighing	**Waste Composition Analysis**	**Surveys**	**Diaries**	**Records**	**Observation**	**Mass balance**	**Proxy Data**	**Literature Data**
ES_1	RFS (Schools)		PP Manufacturing RFS(Canteens and schools)	Households		RFS (Canteens and schools)			RFS (Canteens)
ES_2			Households	Households					
FI_1				Households					
FI_2				RFS					All chain
FI_3	RFS		RD	Households				Manufacturing	Manufacturing
FI_4			PP						
FR_1			All chain					All chain	All chain
HR 1								All chain	
HU_1									Manufacturing RD, RFS, Households
HU_2				Households					
IE_1	RD				RD				
IT_1									PP, Manufacturing RD, Households
LU_1		Households	Manufacturing RD, RFS					RD RFS	Manufacturing RD, RSF
LV_1			Households						
LV_2			Households						
MT_1		Households							
MT_2			Households						
NL_1							All chain		

Study code	Direct methods						Indirect methods		
	Weighing	**Waste Composition Analysis**	**Surveys**	**Diaries**	**Records**	**Observation**	**Mass balance**	**Proxy Data**	**Literature Data**
NL_2									All chain
NL_3			Households						
NL_4		Households	Households						Households
NL_5					RD				
NO 1			Manufacturing Households		RD			Manufacturing	
NO_2		Households							
NO_3			PP						
PL_1					RD				
PT_1			All chain				Production Manufacturing RD		
PT_2	RFS								
RO_1			Households						
SI 1			RFS					PP, RD, Households, RFS	
SI_2								All chain	
SE_1								RD, RFS Households	
SE_2			PP						
UK 1	RD	Households	Households RFS	Households				Manufacturing RFS	RFS
UK_2	RD				RD				
CE_1	RD				RD				

Two studies conducted in Austria were analysed, covering the RFS (AT_1) and the RD (At_2) stages. In the former, data was collected from 29 hospitality companies including gastronomies, hotels and canteen kitchens that registered the food waste divided into 5 distinct areas according to its origin, namely storage loss, loss during kitchen preparation, unserved meals, plate leftovers, and buffet table loss. In the latter, data was collected through records provided by five companies, which have a market share of 83% and represent the major part of the food retail sector in Austria.

Study BE_1, conducted in the region of Flanders (Belgium), comprehensively quantifies food waste along the FSC, including the calculation of the 'cascade index' that reflects the amount of food waste valorised. The study has the particularity of analysing food waste generated by fisheries, including the amounts of fish that is discarded at sea, and food waste produced in auctions[6]. The study uses a combination of methods and, as pointed out in the report, the figures on food waste and food losses at different stages of the chain cannot be compared. Each sector has its specific context, which brings with it differences in order of magnitude, composition, causes and opportunities for prevention and valorisation of food waste.

Data on food waste generated by the food industry was collected from surveys of food companies looking at food losses and their destinations and from audits of food companies in which food losses and their causes were inventoried. Every two years, companies from the food industry were questioned by the Public Waste Agency of Flanders (OVAM) about the quantity and destination of 'food waste' in their company in connection with the Integrated Environmental Report. Specifically for food waste, OVAM uses the statistical module 'Food Waste Plug-in', developed at European level. Companies are required to record the data and submit them to OVAM. At retail level, a combination of records (i.e. sales figures) and data collected through a survey were used to quantify food waste.

Additional studies conducted in Flanders quantified the share of losses in the horticultural stage due to cosmetic reasons using surveys (BE_2) and the amount of household food waste using surveys and diaries (BE_3). In BE_2, 299 farmers and horticulturists filled in an online survey. In BE_3, 1,031 Flemish households were asked about the quantity, composition, and final destination of the discarded food during one year. In addition, the study inquired about the reasons for throwing away food.

The study reporting the amounts of food waste for Czechia along the FSC (CZ_1) uses data from the literature, taken from Priefer et al.(2013), based on the SIK-methodology (Gustavsson et al. 2013), and from Monier et al. (2010).

One of the studies analysed for Germany (DE_1) used data from the literature in their quantification, including data from study DE_2. The latter uses a combination of direct and indirect methods. Surveys were used to quantify food waste in the food industry in consultation with the Federation of German Food and Drink Industries (Bundesvereinigung der Deutschen Ernährungsindustrie (BVE)). The questionnaire was distributed by the BVE and affiliated trade associations. In addition, a revised questionnaire was distributed directly to most food business operators. At retail, existing literature on trade (national and international studies, statistics, etc.) was analysed. These results were transferred to Germany with due regard to the methods used in each case. In order to verify the database generated, trade associations for retail trade and for wholesale markets and other relevant stakeholders (e.g. food waste disposal firms) were contacted. Knowledge gained from these expert consultations and complementary on-the-spot checks were taken into account. To quantify the amount of food waste generated by restaurants and food services, the triangulation method (that refers to a combination of more than one approach to produce results) was used. Therefore, several calculation approaches were developed for the individual types of management of food

[6] Auctions are quite particular of the Flemish context. Producer organisations play a major role in the Flemish chain of vegetables and fruit for the fresh market, occupying a central position between the horticulturalists who deliver their product (supply) and the wholesalers and retailers who buy these products (demand).

services. Household food waste was extrapolated from data on waste collection analyses in Germany and from comparable national and international studies. The extrapolation was based on waste data (amounts and composition of waste).

EE_1 quantified the food waste generated by households using a detailed diary, recording the weight and types of food waste from 100 households, and a structured questionnaire. The study included different types of typical households in Estonia with various income levels and living arrangements. Additionally, the study quantified food waste generated by 20 catering institutions: three restaurants, three bars/pubs, three cafés, four canteens/buffets, three schools, three kindergartens and one hospital. The generation of food waste and food loss was measured in each institution during five days and in different phases: preparation, serving, consumption and storing of food. Different types of food waste were collected in separate containers which were weighed at the end of each day during the study. In addition, data on the number and average weight of served portions was collected.

To estimate the food waste generation by Greek households (EL_1), a diary was distributed to 252 households in various urban and semi-urban areas of the country, namely Athens, Heraklion and Chania in Crete, during the second semester of 2013. The participants were asked to fill in the diary after weighing the food that was going to be wasted. The diary had different sections referring to breakfast, lunch, and dinner. In addition, the consumer was asked to identify the food waste generated during the preparation of the meal and after its consumption. In study ES_1 food waste at primary production was quantified through 319 phone interviews. Questionnaires were send to 300 food manufacturing companies, of which 60 completed it. A combination of methods was used at consumption stage, depending on the activity covered. For example, weighting, surveys, and observation were used for the quantification of food waste generated in schools. For households, data was collected from 4,000 households through online questionnaires, assessing their shopping (2,000 households) and user (2,000 households) profiles. In study ES_2, the number of households considered for the shopping profile was 12000 covering the different regions of Spain. The user profile was obtained from 4000 households that filled in an online diary reporting their consumption at home.

Study FI_1 reports data from household food waste obtained through the participation of 380 households that weighted and reported data on avoidable food waste. Study FI_2, estimated food waste generation at RFS, thanks to the participation of 72 restaurants in which staff kept a diary and weighed the food produced and wasted in a one week period. Study FI_3, quantified food waste generated by the food industry, collecting data from the Finnish food companies that participated in the study, as well as from the literature and some corporate responsibility reports. At retail, data was collected from interviews with four retail chain representatives (covering 90% of the food markets), one waste management representative (Helsinki Region Environmental Services Authority) and a member of the Finnish Grocery Trade Association. Food waste generated by households was obtained from kitchen dairies mapping the volume and composition of food waste. For the RFS, the study covered 17 catering businesses and 72 restaurants, that weighted the waste generated during cooking and serving, as well as customer leftovers.

Study FR_1 combined different methods to consolidate data. Data was collected from actors in food and consumption, carrying out 512 quali-quantitative interviews (distributed along the different stages of the FSC) and 70 qualitative interviews. The data collected was complemented and verified with literature data, and with the collaboration of experts and stakeholders in the preparation of the report.

HU_2 gathered data on solid and liquid food waste recorded from 100 households for one week by using diaries. According to the authors, although the sample size is relatively small, the collected data are approximately representative of the Hungarian households in regard of average household size, NUTS 1 regions of Hungary, and presence of children in the households.

IT_1 estimated the amounts of food waste as a share of the agricultural production remaining in the fields calculated as the difference between the total production (in tonnes) minus harvested production. An estimate of the waste was obtained by comparing the amount of food available to every Italian by product type, as reported by FAO (food balance sheets), with the consumption of food per capita per day, as reported by National Research Institute for Food and Nutrition. The food surplus is calculated as the difference between how much food is potentially available and what is actually consumed. A significant portion of this figure was classifiable as waste.

Studies LV_1 and LV_2 quantified food waste generated by households through surveys. The first quantified food waste as a percentage of food purchased amounts, whilst the second estimated the total amount of food wasted.

Household food waste in MT_1 was quantified through a waste composition survey carried out through a random sample of 700 households held in July and October 2011, and in April 2012, for one week in every month to account for seasonal variations.

A mass balance approach was used in study NL_1, estimating food flows along the entire FSC. Herein, a three-layer approach was adopted by mapping (i) the food chain, (ii) the secondary resources and (iii) their destinations. The secondary resources are the parts of food that leaves the regular food stream and were categorized as follows: avoidable, potentially avoidable, unavoidable food waste or by-products. The destination of the secondary resource flows included food banks, cattle feed production or incineration. Other studies conducted in the Netherlands, quantified household food waste using surveys (183 respondents) (NL_3) and a combination of data collected from surveys and waste composition analysis (NL_4)

The food waste generated by the food industry in Norway, as presented in NO_1 was calculated using data collected from companies, covering about a quarter of total sales in the Norway, through surveys and proxy data. 15 companies provided data for 2016, and 11 of these have provided data every year since 2010. The amount of food waste generated was calculated by multiplying the production volume by the percentage of waste recorded by the reporting companies by product group and year. Food waste from the fishing industry, brewery industry and in mills and flour producers, was not calculated because the data from these sectors was of poor quality or it was not available. The wholesalers providing data on food waste covered a significant share of Norwegian wholesale companies. For retailers, 89 stores from three chains have provided data. The market share in the retail sector for the wholesalers and for the stores considered were used to upscale amounts to national level.

Additionally, surveys were conducted to quantify household food waste across a sample of 1,000 respondents representative of Norwegian consumers. The compositional analyses used in NO_2 to calculate household food waste covered 47% of the total population in Norway, and 12 out of 19 Norwegian municipalities/regions. Information on waste amounts was combined with the composition of the waste streams to calculate the amount and composition of food waste as a basis for upscaling to national statistics.

The estimation of food waste in the Portuguese supply chain (PT_1) was based on a mass flow study, using data from the Agricultural Statistics. The mass flow of the supply chain was built through the application of losses at each stage of the chain. This information and other data were collected by conducting approximately 70 interviews with producers, industry, and retailers, and also through an online survey to which 804 families responded.

Surveys were also used in RO_1, collecting data from 960 respondents (902 validated) from 153 cities.

Food waste amounts in studies SI_1 and SI_2 were estimated from national waste statistics and estimates of the share of food waste within mixed fractions of waste. The analysis was prepared on data for the years 2013, 2014 and 2015.

UK_1 provides a baseline for food waste in the UK with updated estimates of the quantity of food waste arising in 2015. Household food waste collected by local authorities was estimated by combining local authority waste compositional analyses with WasteDataFlow[7] information on the quantities collected in each waste stream. 85% of retail sector sales value provided data on their food waste and the retail baseline has been calculated by upscaling the signatory food waste data to account for the whole sector. At manufacturing, the food waste was calculated using the total amounts of waste arising from manufacture (obtained from Environment Agency Integrated Pollution Prevention and Control), including all wastes arising by European Waste Catalogue code. Then, fieldwork was used to estimate the amounts of food waste in each sector/EWC code. Data was scaled up to UK level using data on the number of premises by employment band for each subsector.

The studies conducted by Tesco (IE_1, UK_2, and CE_1), included the collection of primary data from their stores and depots from several sources including: (i) products that were damaged in the store, whether on the shop floor or in storage, including waste arising from customer returns and from clearance events; (ii) products that exceed the 'Best before' or 'Use by' date and could no longer be sold; (iii) products that were not suitable for sale, and (iv) products that were damaged during an exceptional event. For example, this waste could be caused by a fridge breakdown or a flood.

The number of units wasted per item was then converted into a weight measured in tonnes. A 'bottom up' calculation was performed from the waste tonnages of individual products (e.g. Gala Apples), to the waste associated with each commercial food category (e.g. produce), to the entire waste generated by country operations. Waste tonnages were added to obtain totals by category and for the entire country operations. To assign a unit weight to each product, the weight reported on the packaging was used whenever available. In all the other cases (e.g. baguettes or food in the deli counter) primary data was collected to obtain the average weight of a product.

[7]web based system for municipal waste data reporting by UK local authorities to government

3.4 Quantification results

This section presents the amounts of food waste reported in the studies in absolute terms and normalised (section 3.4.1) and a detailed analysis per stage of the FSC (section 3.4.2). The studies identified as case studies are reported in section 3.4.3.

3.4.1 Overview of the food waste amounts reported

The total amounts of food waste reported by each study per stage of the FSC are presented in Table 7. To enable a comparison between the amounts reported by the different studies, the food waste reported for each stage was normalised using an appropriate normalisation factors for each sector (FUSIONS, 2016b). For primary production, this was the total amount of primary crops produced in each country, obtained from FAO (2018). At processing and manufacturing, the normalisation factor was the produced amount of manufactured food items, taken from Prodcom (EUROSTAT, 2011). At the remaining stages the values of food waste were normalised considering the population of each country. The resulting values are reported in Table 8. For studies that reported values of food waste per capita, the total food waste at country level was derived. For studies reporting the total food waste across the FSC and the share of food waste at each stage, the food waste generated at each stage was derived. The values that were derived are reported in red in the respective tables, while values taken directly from the study are reported in black.

Countries for which no study was found are Bulgaria, Cyprus, Ireland, and Lithuania. For these cases, a source of information can be the reference studies that accounted for food waste in the MS countries already mentioned in section 1: Bräutigam et al. (2014), Monier et al (2010), and FUSIONS (2016). Detailed results of these studies are presented in Annex 1.

As shown in Table 7 and Table 8, studies that have provided a quantification of food waste along the FSC are BE_1, DK_2, FR_1, HR_1, NL_1, NL_2, NL_4, PT_1, SI_1, and SI_2. Figures range from about 120,000 to about 3,500,000 tonnes.

A study for Slovenia (SI_2) reports data for 2013, 2014, and 2015, showing an increase in the amount of food waste generated in every stage of the FSC. For Norway, study NO_1, that presents data for 2010 to 2016, shows a decrease in the amount of food waste generated at processing and manufacturing from 2010 to 2016, while for retail and distribution no clear trend was observed.

Table 7. Food waste quantified in each study (in tonnes).

Code	Year	Primary Prod.	Processing & Manufact.	Retail & Dist.	Rest. and Food service	Households	Total food chain
AT_1	2014				268,735		
AT_2	2013			74,100			
BE_1	2015	475,031	2,349,445	64,828	127,548	468,305	**3,485,157**
BE_2	2016	120,000					
BE_3	2016-2018					241,092[p]	
CZ_1 [α]	2010		361,813	91,104	122,810	254,124	
CZ_1 [β]	2013	523,056	317,295	121,149		963,423	
DE_1	2010				1,930,533 [p]	6,216,972[p]	
DE_2	2011		1,850,000	550,000	1,900,000	6,670,000	**10,970,000**[+]
DK_1	2011/2012					479,924	
DK_2	2002-2016	100,000	133,000	163,000	60,000	260,000	**716,000**
DK_3	2010-2013	117,000					
EE_1	2014				22,000	96,000	
EE_3	2015		3,392	6,200			
EL_1	2013					1,088,258[p]	
ES_1	2014-2016					1,240,000	
ES_2	2017					1,229,509	
	2016					1,303,960	
FI_1	2017					120,000-160,000	
FI_2	2010				75,000-85,000		
FI_3	2010		75,000-140,000	65,000-75,000	*75,000-85,000*	*120,000-160,000*	**335,000**[+] **- 460,000**[+]
FI_4	2010-2013	60,000					
FR_1	2015-2016	3,200,000	2,100,000	1,400,000	1,700,246	1,598,978	**10,000,000**
HR_1	2017	19,981*	35,965*	11,988*	23,977*	307,700*	**399,611**
HU_1			1,116,000*	198,000*	108,000*	378,000*	**1,800,000**[+]
HU_2	2016					668,866	
IT_1	2005-2010	17,697,000	1,890,000	263,645			
LU_1	2012-2014			4,950	13,800	49,260	**68,010**[+]
LV_2	2013-2016					108,686	
MT_1	2011-2012					53,663	
MT_2	2002, 2012, 2013					58,258	
NL_1	2011						**1,490,000 - 3,470,000**
	2009					661,000-794,000	**1,380,000 - 2,480,000**

Code	Year	Primary Prod.	Processing & Manufact.	Retail & Dist.	Rest. and Food service	Households	Total food chain
NL_2	2009-2016						**1,781,000 - 2,466,000**
NL_3	2016					359,957	
NL_4	2016					1,056,101	
	2013					1,080,605	
	2012						**1,700,000 - 2,600,000**
	2010					1,092,292	
NO_1	2016		76,515	68,449			
	2015		74,446	63,245			
	2014		76,944	59,503			
	2013		85,070	63,174			
	2012		80,324	63,326			
	2011		91,242	68,360			
	2010		87,073	69,443			
NO_2	2015-2017					222,025	
NO_3	2010-2013	61,000					
PT_1	2011-2012	332,000	77,000	298,000	included in households	324,000	**1,030,000**
RO_1	2016					898,885	
SE_1	2016			30,184	143,816	774,616	**949,000**⁺
	2014			30,184	135,000	770,000	**935,000**⁺
SE_2	2010-2013	98,000					
SI_1	2017	10,485	included in primary production	13,115	40,568	67,594	**131,761**
	2016	10,726		14,492	43,899	68,521	**137,638**
	2015	10,001		12,933	44,824	66,141	**133,898**
	2014	9,516		9,478	41,348	64,761	**125,102**
	2013	7,950		9,165	38,313	63,023	**118,450**
SI_2	2015	36,691	included in primary production	13,438	27,782	73,080	**150,991**
	2014	34,208		10,772	29,114	71,474	**145,568**
	2013	27,692		9,626	26,505	68,043	**131,866**
UK_1	2015		1,850,000	261,000	1,020,000	7,050,000	**10,200,000**⁺

The cells in grey refer to stages covered by the study but for which figures were not provided and the values in red were calculated from the per capita value.
*figures calculated according the share of the total food waste provided in the report; ⁺ values calculated as the sum of the stages considered in the study and not including the FSC; ᵅ based on Monier et al. 2010; ᵝ based on Priefer et al. 2013.

Table 8. Food waste amounts normalised.

Code	Year	Primary Production*	Processing & Manufacturing*	Retail & Distribution**	Restaurants and Food service**	Households**
AT_1	2014				32	
AT_2	2013			9		
BE_1	2015	47	101	10	30	73
BE_2	2016	23				
BE_3	2016-2018					37
CZ_1 [α]	2010		23	9	12	24
CZ_1 [β]	2013	34	20	12		92
DE_1	2010				24	76
DE_2	2011		11	7	24	84-95
DK_1	2011/2012					86
DK_2	2002-2016	7	9	29	11	46
DK_3	2010-2013	8				
EE_1	2014				17	54
EE_3	2015		2	5		
EL_1	2013					99
ES_1	2014-2016					27
ES_2	2017					26
	2016					28
FI_1	2017					23
FI_2	2010				14-16	
FI_3	2010		12	12-14	14-16	22-30
FI_4	2010-2013	12				
FR_1	2015-2016	27	16	21	25	24
HR_1	2017	3	8	3	6	75
HU_1			66	20	11	39
HU_2	2016					68
IT_1	2005-2010	312	17	4		
LU_1	2012-2014			9	25	90
LV_2	2013-2016					55
MT_1	2002, 2012, 2013					129
MT_2	2002, 2012, 2013					139
NL_1	2009					40 - 48
NL_3	2016					21
NL_4	2016					62
	2013					64

Code	Year	Primary Production*	Processing & Manufacturing*	Retail & Distribution**	Restaurants and Food service**	Households**
	2010					66
NO_1	2016		5	11		
	2015		5	12		
	2014		5	12		
	2013		6	13		
	2012		5	13		
	2011		6	14		
	2010		6	14		
NO_2	2015-2017					43
NO_3	2010-2013	32				
PT_1	2011-2012	51	4	28	included in households	31
RO_1	2016					45
SE_1	2016			3	15	79
	2014			3	14	80
SE_2	2010-2013	11				
SI_1	2017	10	included in primary production	6	20	33
	2016	10		7	21	33
	2015	9		6	22	32
	2014	9		5	20	31
	2013	7		4	19	31
SI_2	2015	34	included in primary production	7	13	35
	2014	32		5	14	35
	2013	26		5	13	33
UK_1	2015		21	4	16	108

The cells in grey refer to stages covered by the study but for which figures were not provided and the values in red were calculated from the absolute value (table 7).
* kg of food waste per tonne of production; ** kg of food waste per capita; [α] based on Monier et al. 2010; [β] based on Priefer et al. 2013.

3.4.2 Results per stage of the FSC

An overview of the normalised amounts of food waste reported by the different studies at each stage of the FSC is provided in Figures 6 - 10. For studies reporting results for more than one year (Table 8), the most recent value is reported in Figures 6-10. 14 studies provided figures on food waste at primary production (Figure 6), 14 at processing and manufacturing (Figure 7), 19 at retail and distribution (Figure 8), 16 at restaurant and food services, and 19 at the household level.

As shown in Figures 6 to 10, there is a large variability in the amounts of food waste reported by the different studies. A number of outliers, i.e. values that are significantly higher or lower than the remaining ones, can be found across the five figures. This might be due to different food waste profiles of the countries, or due to different accounting approaches adopted. A more detailed analysis of the results obtained for each stage is presented in the following sections.

3.4.2.1 Primary production

According to Figure 6, the amount of food waste at primary production reported in the different studies ranges from 3 to 312 kg of food waste per tonne of production. The value for Italy (312 kg per tonne produced) is significantly higher than all the remaining ones (between 3 and 51 kg per tonne produced). This value refers to the share of the agricultural production remaining in the fields that was calculated as the difference between the total production (in tonnes) minus harvested production. Studies on the amounts of food that is left in the fields are practically inexistent which makes it very difficult to assess if this value is under/over estimated. On the other hand, HR_1 presents the lowest value (3 kg per tonne produced). This figure is based on available statistical data, and was estimated by calculating the quantities and composition of mixed municipal waste separately for certain sectors that produce food waste, assuming that 5% of the total food waste happens at the primary production. No information is provided on how this percentage was determined.

Some of the studies provided a split between edible and inedible food waste (Figure 6). Similar results on amounts of edible food waste were obtained by FR_1 (27 kg per tonne produced), CZ_1(β) (34 kg per tonne produced), and BE_1 (35 kg per tonne produced). Lower amounts of edible food waste were obtained for DK_2 (7 kg per tonne produced and SI_2 (12 kg per tonne produced).

Studies carried out in the same country/region present some discrepancies. BE_1 presents approximately the double (47 kg per tonne produced) of the amounts reported BE_2 (23 kg per tonne produced). This is explained by the fact that the studies had different scopes: BE_1 refers to food waste originated in fishery, agriculture, and auctions, whilst BE_2 accounted for food waste generated in the horticulture only due to cosmetic reasons. SI_2 presents values 3 times higher than SI_1 because it includes in the primary production the amounts of food waste generated at the processing and manufacturing stage. DK_2 and DK_3 present similar results (7 and 8 kg per tonne produced) although DK_2 refers only to edible food waste whilst DK_3 considers both, edible and inedible.

3.4.2.2 Processing and Manufacturing

Amounts of food waste generated at the processing and manufacturing range between 2 to 101 kg per tonne of production (Figure 7). Figures reported by BE_1 (101 kg per tonne produced) and HU_1 (66 kg per tonne produced) are significantly higher than the figures reported in the other studies (2 to 22 kg per tonne produced). The larger contribution to the amounts reported in BE_1 is the inedible parts of food (about 90% of the 101 kg per tonne produced). Regarding HU_1, the figure refers to about 60% of the total amount of food waste generated in Hungary. Although covering several food-processing industries (meat, fish, cereals, dairy, bakery, beverage) values reported in EE_3 are relatively small (2 kg per tonne produced), referring to both edible and inedible parts of food. This figure was obtained from data on 39 companies that provided data the Environment Agency's Waste Reporting Information System.

Figure 6. Food waste at primary production divided by the total production of primary crops for each country (FAO, 2018) [kg of food waste per tonne of production].

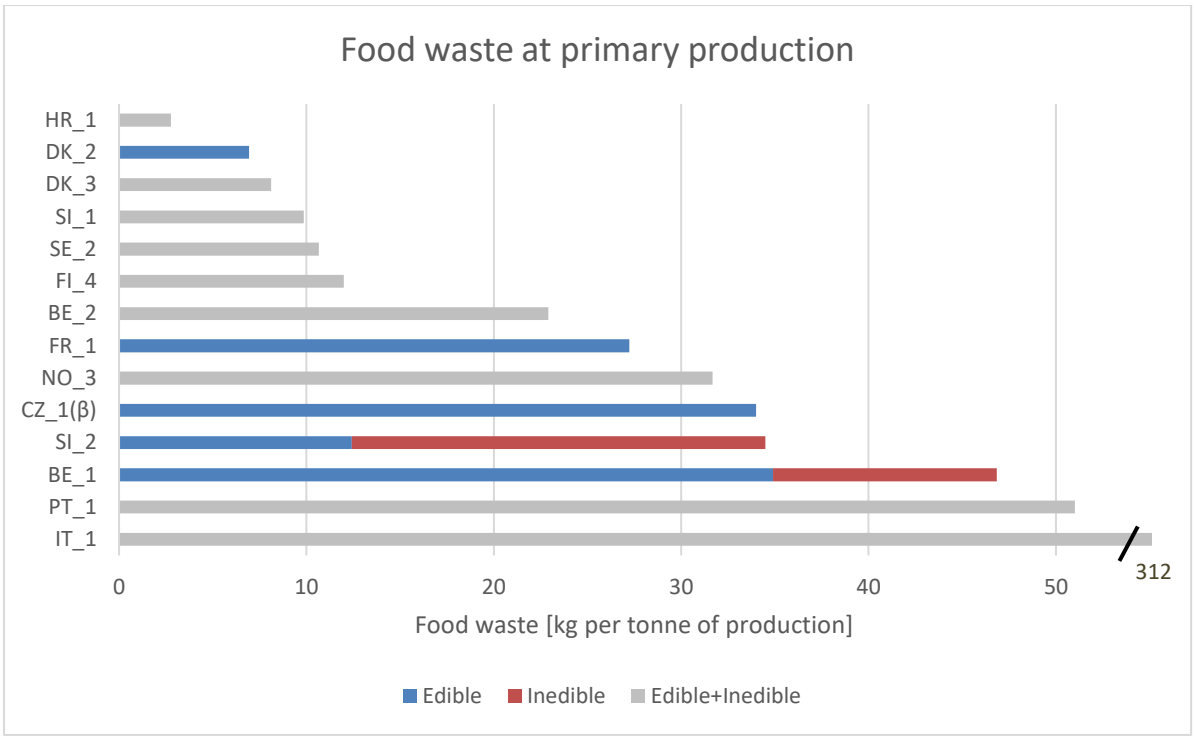
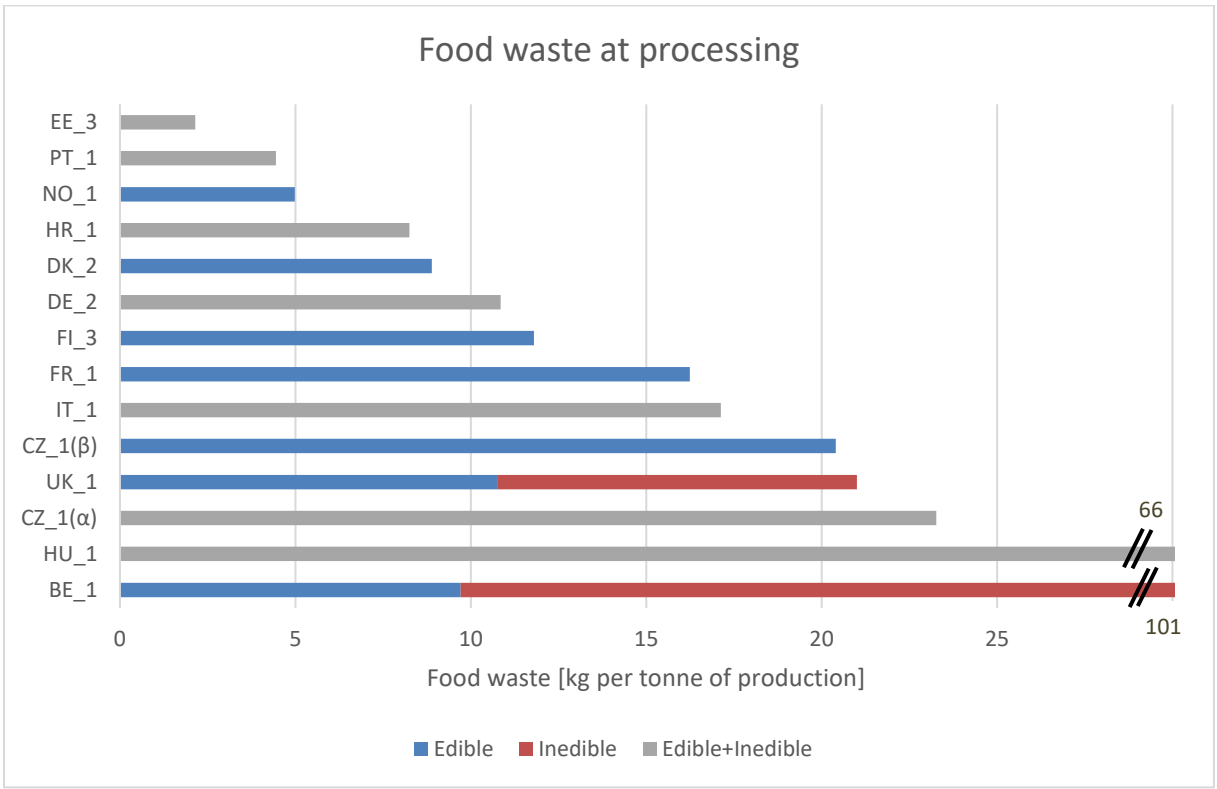


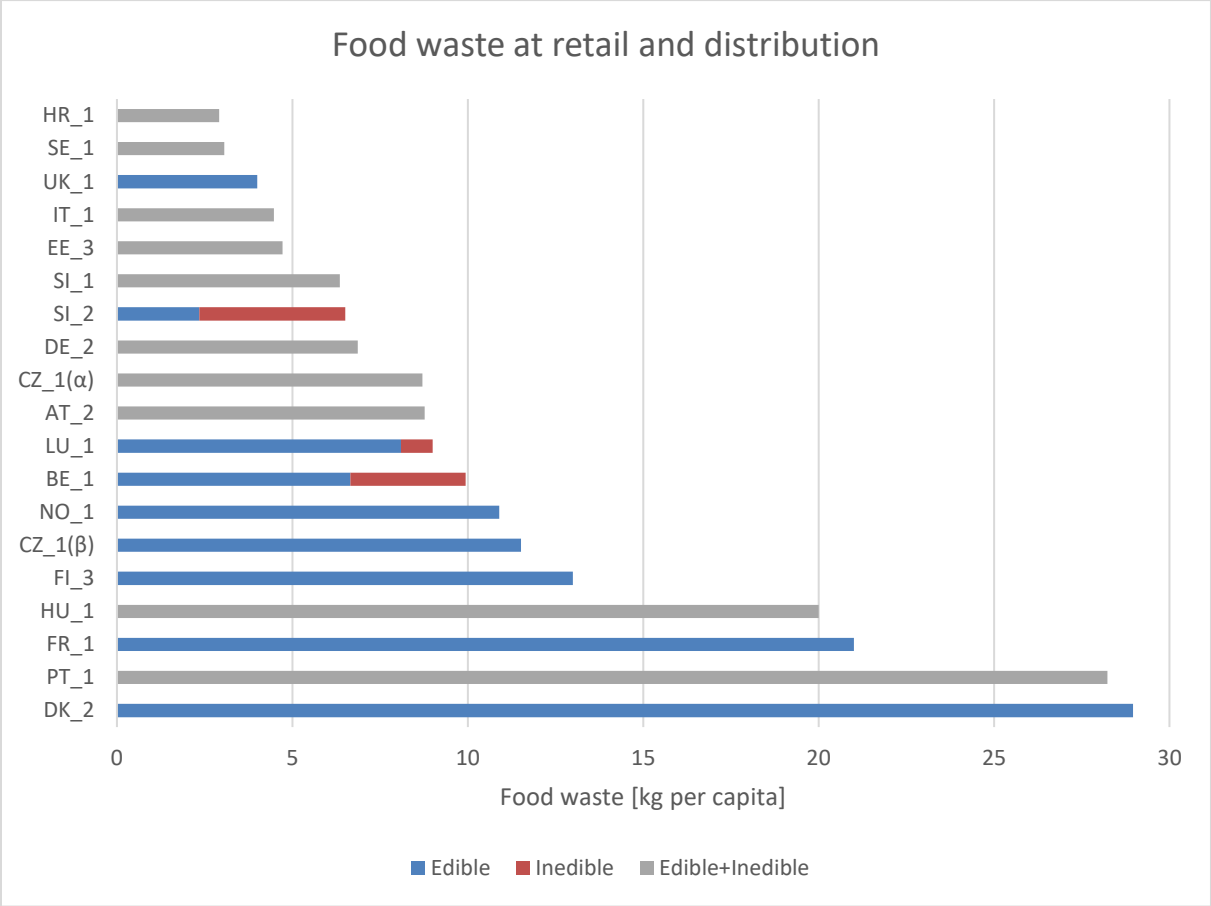
Figure 7. Food waste at processing and manufacturing divided by the total production of manufactured food (EUROSTAT, 2011) [kg of food waste per tonne of production].



3.4.2.3 Retail and Distribution

Amounts of food waste generated at retail and distribution (Figure 8) range from 3 to 29 kg per capita. The highest amounts were reported by DK_2 (29 kg per capita) and PT_1 (28 kg per capita). Although these studies report similar amounts, DK_2 refers only to edible parts of food whilst PT_1 to both edible and inedible. Besides DK_2, other studies reporting only edible parts of food are FR_1 (21 kg per capita), FI_3 (13 kg per capita), CZ_1 (β) (12 kg per capita), NO_1 (11 kg per capita), and UK_1 (4 kg per capita). Both studies for Slovenia (SI_1 and SI_2) present similar amounts, 6 and 7 kg per capita. HR_1 is the study reporting the lowest amounts of food waste at retail and distribution (3 kg per capita).

Figure 8. Food waste at retail and distribution level [kg per capita per year].



3.4.2.4 Consumption: Restaurants and food services sector, and households

Figure 9 shows the amounts of food waste generated in the restaurants and food service sector and Figure 10 household food waste.

For restaurants and food services, the amounts range from 6 to 32 kg per capita, with the lowest amount reported by HR_1 (6 kg per capita). The highest amounts are reported by AT_1 (32 kg per capita) and BE_1 (30 kg per capita). Studies carried out in Germany, DE_1 and DE_2 presents the same value: 26 kg per capita. DE_1 used data from the literature in their quantification, including data from DE_2, which may explain the similarities. For Slovenia, the values presented in SI_1 and SI_2 are different: 20 kg per capita and 13 kg per capita, respectively.

Household food waste (Figure 10) ranges from 21 to 139 kg per capita. The highest amounts are reported by MT_2 (139 kg per capita) and UK_1 (108 Kg per capita). Studies

conducted in Germany, DE_1 and DE_2, reported values that do not differ significantly: 76 kg per capita in DE_1 and 90 kg per capita in DE_2. Similar values were reported for studies carried out in Slovenia (33 kg per capita in SI_1 and 35 kg per capita in SI_2) and Spain (27 kg per capita in ES_2 and ES_1). On the contrary, for Flanders, the values reported in BE_1 (73 kg per capita) are almost the double of the values reported in BE_2 (37 kg per capita). This can be explained by the fact that BE_3 reports only edible parts of food whilst BE_1 includes both edible and inedible components. The studies for the Netherlands also show some discrepancies. NL_4 reports 62 kg per capita, NL_1 42 kg per capita, and NL_3 21 kg per capita. Amounts reported in NL_4 refer to both edible and inedible parts of food, whilst NL_1 and NL_3 only edible. NL_1 uses a mass balance approach to quantify food waste and in NL_3 data was collected through surveys. As pointed out by van Herpen et al. (2019) and Cicatiello and Giordano (2018), the collection of data using surveys may lead to underestimated data, which can explain the lower value reported by NL_3 compared to NL_1.

In their review, Cicatiello and Giordano (2018) also observed a large variability of the amounts of food waste generated by households, with values ranging from only 5 to over 100 kg of food waste per person per year. According to the authors such variety is due to the definitions of food waste adopted (limiting or not the focus on edible food waste), as well as to the different methodological approaches (Cicatiello and Giordano, 2018).

Figure 9: Food waste at restaurant and food services level [kg per capita per year].

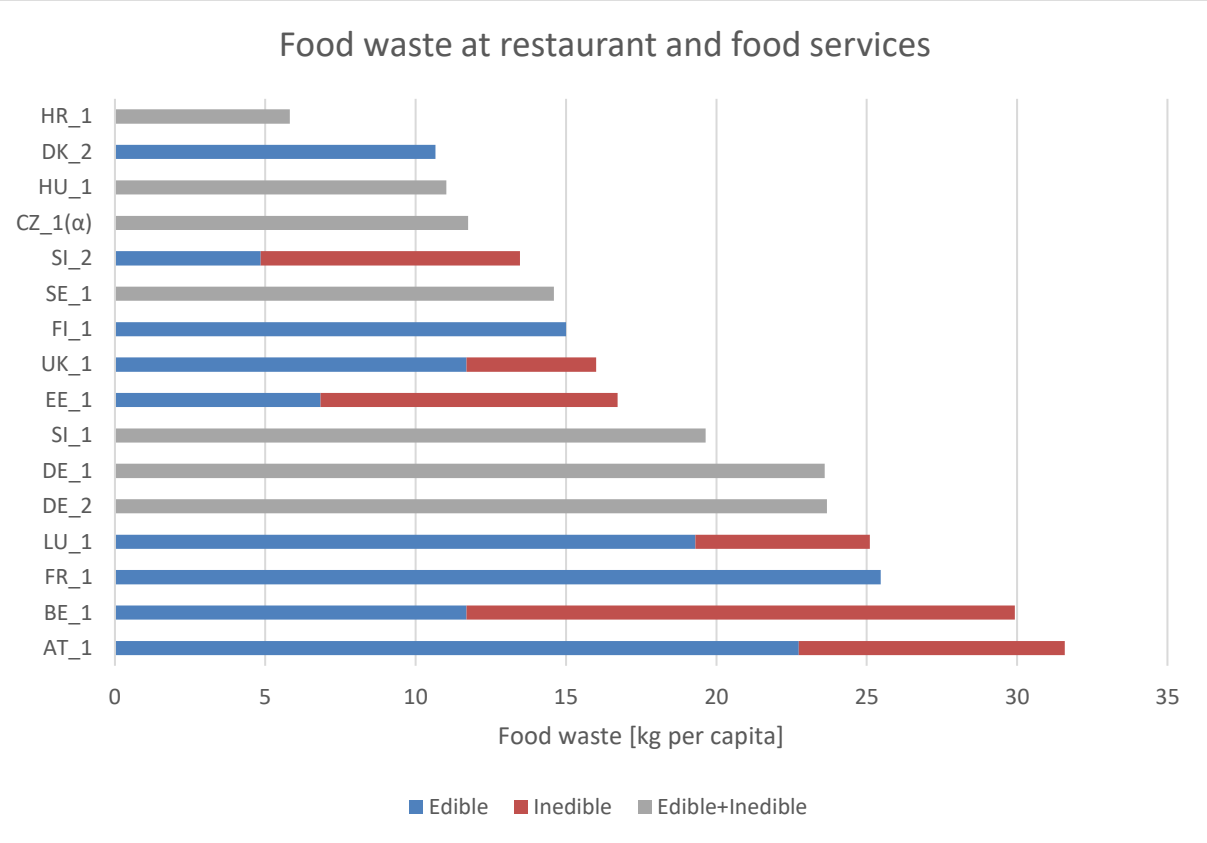
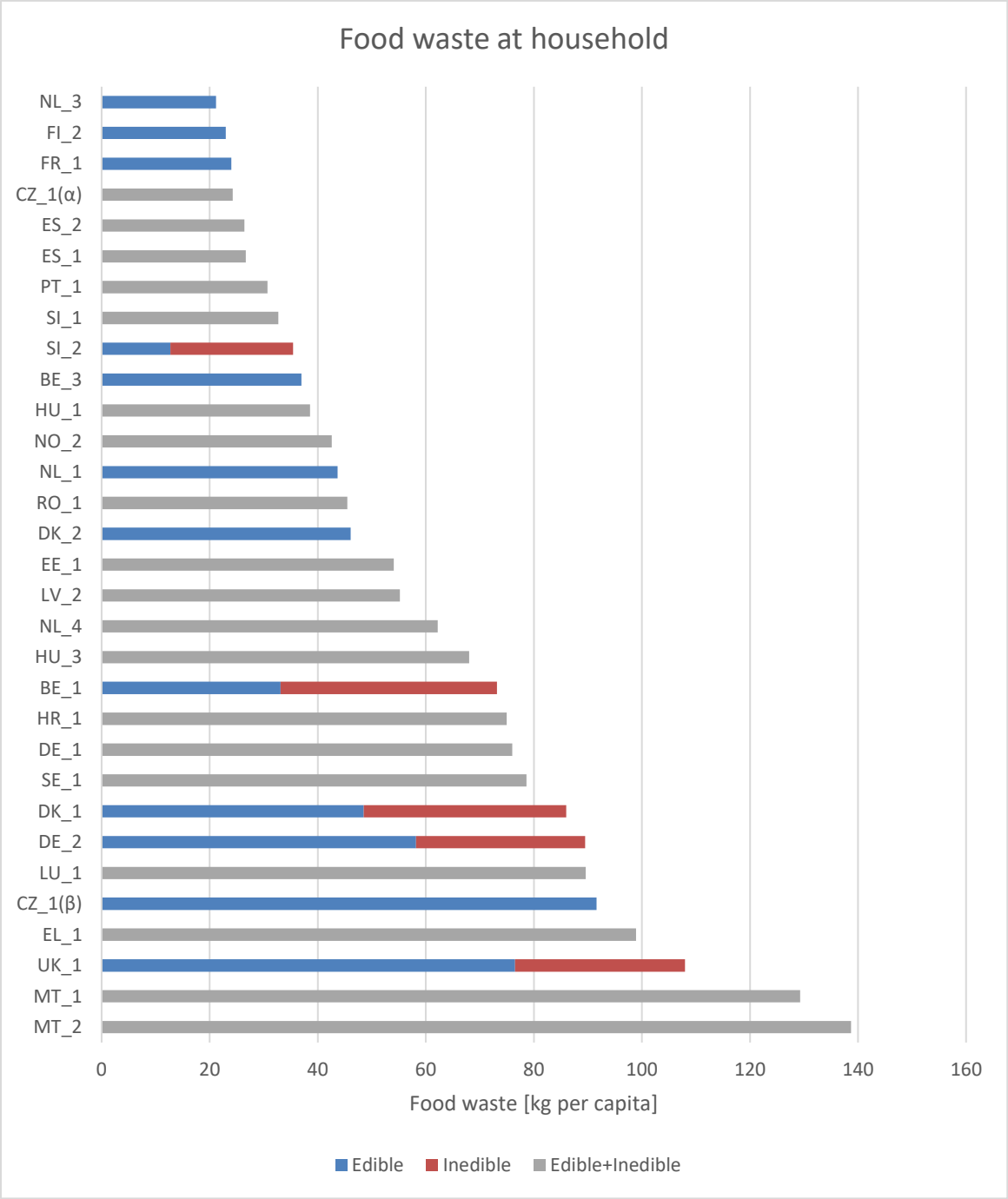


Figure 10: Food waste at household level [kg per capita per year].



3.4.3 Case studies

Out of the 48 studies analysed, 6 (PL_1, PT_2, NL_5, UK_2, IE_1 and CE_1) were classified as case studies. In other words, unlike the other studies that were conducted at national level (with the exception of studies BE_1, BE_2 and BE_3, that were conducted in the Flanders region), these studies were specifically focused on one sector of the FSC and in most cases on one single actor (e.g. one supermarket). The list of case studies included in this analysis is by no means comprehensive, and they were selected to improve the coverage of some of the sectors of the FSC that were considered to be less represented in the studies conducted at national level.

Study PT_2 quantified the food waste generated in one hospital in Portugal for 8 weeks, focusing on the plate waste only. In this period of time approximately 8000 meals were

served, and 35% of the food was wasted, equal to 953 grams per patient per day. Specifically, 12% of the soup, 52% of the main course, 54% of the bread and 18% of the fruit were wasted on average.

Studies PL_1 and NL_5 were both focused at retail level. PL_1 reported the amounts of unsold food by a supermarket in Poland (sales area of 2000 m^2) over two weeks distinguishing by product group. In total, 3.3 tonnes of unsold items were recorded, of which more than half were vegetables (24.2%), fruit (14.9%) and meat and fish (12.5%). Liquid items contributed to 18% of the total. NL_5 focused on three products sold by a supermarket in the Netherlands, reporting the percentage of sales that were wasted (between 8% and 30%).

Studies IE_1, UK_2 and CE_1, were conducted by the retail chain Tesco, referring to food waste generated by the activities of this company in Ireland, UK, and Central Europe (Czech Republic, Hungary, Poland and Slovakia). The results of each study are reported in Table 9. Additionally, the contribution of different product groups to the total food waste generated was reported in the three case studies, showing that the product group wasted in larger quantities was produce (i.e. fresh fruit and vegetables), contributing to 31%-35% of the total.

Table 9. Results of the three case studies reported by Tesco for the financial year 2017/2018

Case study	**IE_1**	**UK_2**	**CE_1**
Country	Ireland	UK	Czech Republic, Hungary, Poland, Slovakia
Surplus food (tonnes)	7,762	73,340	51,579
of which donated (tonnes)	976	7,975 + 337*	10,639
of which used for animal feed (tonnes)		10,688	2,510
of which wasted (tonnes)	6,786	53,126	38,054
Food waste as % of sales	1.2%	0.5%	1.2%

* this amount was offered to Tesco's employees

3.5 Food waste destinations

The majority of the studies did not provide any type of information on the destinations of surplus food and food waste. The information available is reported in Table 10 for those studies focusing on household food waste and in Table 11 for the remaining studies. It is important to highlight that not all the destinations reported in the following tables are considered food waste destinations in the delegated act (e.g. anima feed), nevertheless all those reported by the studies analysed are included in the tables for completeness.

It is possible the see that the destinations of food waste vary significantly across studies, countries and stages of the FSC. In some cases (e.g. Flanders region, the Netherlands, Slovenia) a significant part of the food waste is valorised either as animal feed, for composting, or anaerobic digestion. The valorisation of horticultural waste for alcohol production was reported as a common practice in Italy and the Netherlands. Finally, home composting and feeding food waste to pets was reported by studies assessing food waste at household level in Hungary and the Flanders.

Few studies reported the amount of food waste used for home composting. SE_1 reports that 42,900 tonnes food waste was home-composted in 2016, roughly equal to 4.4 kg per person per year. UK_1 states that home composting is a relatively minor route for

discarding food waste (8 kg/person/year). This estimation was based on a study conducted in 2012 that involved 948 households making use of kitchen diaries. LU_1 reports that 4.286 tonnes of food waste per year (total) are home-composted, equal to about 1.5 kg/person/year.

Table 10: Destinations of household food waste as reported in the studies analysed.

	BE_1	BE_3	EL_1	HU_2	NL_1	NL_3	UK_1
Animal feed	28%					5%	
Incineration	24%				75%		
Composting	40%		2%		23%	25%	
Home composted / Pet food		45%		37%		2%	7%
Landfill	3%		98%		2%		
Sewer						30%	23%
Anaerobic digestion	6%						
Residual waste/non specified		55%		63%		38%	69%

Table 11: Destinations of surplus food/food waste across the FSC as reported in the studies analysed.

	BE_1	FR_1	IT_1*	NL_1	NL_2	SI_2
Donation			5%			
Animal feed	43%		4%	21%	16%-22%	
Energy generation	5%					
Incineration	6%			46%	37%-38%	
Composting	6%	37%	55%	22%	28%-32%	25%
Anaerobic digestion	21%					43%
Landfill	1%			3%	1%-5%	15%
Plough-in	17%					
Alcohol distillation			36%	8%	10%	
Other	1%	63%				18%

* Values provided for horticultural production only

3.6 Liquid waste

As shown in Table 12, 22 studies reported amounts of liquid food waste. Of these, 5 studies estimated such quantities based on previous literature and/or proxy data, while 17 studies reported primary data collected through surveys or by using kitchen diaries. Four studies collected primary data with a specific focus on capturing the amounts of liquid food waste disposed via the sewer. These are:

- NL_3, which presents the results of an on-line questionnaire (763 respondents) collecting data on the amount of self-reported waste of solid food, beverages and dairy products (disposed via the sink). This study reported an average food waste amount of 21.2 kg per person per year, of which 11.6 kg of solid food, 6.9 litres of beverages and 2.6 litres of liquid dairy products.
- NL_4, where 1,105 respondents used an App to report their food waste generation, three times per day, during both weekdays and weekends. The following types of

liquid food were included in the study: milk and/or buttermilk, dairy drinks, fat dairy products, soft drinks and/or juices, coffee and/or tea, sauces. This study quantified 47 kg per person per year of solid food waste and 57 litres per person per year of liquid food waste (of which the main contributors were 30.7 litres of coffee and tea, 10.2 litres of milk, and 2.6 litres of dairy drinks).

- UK_1 accounted for liquid food waste disposed through the kitchen sink using the method outlined in WRAP (2013). The data was collected through kitchen diaries, where participants (319 households) recorded the amount of food and drinks disposed down the drain. According to this study, 25 kg of food waste per person per year went to the sewer.

Table 12. Overview of studies reporting liquid food waste, stages of the FSC for which it was reported and quantification method adopted.

Study	Stage(s) of the FSC	Method
AT_1	Food services	Weighing
AT_2	Retail	Records
BE_1	Households	Literature/proxy data
BE_3	Households	Kitchen diaries
DE_1	All	Literature/proxy data
DE_2	All	Literature/proxy data
DK_2	Households	Literature/proxy data
EE_3	Manufacturing, retail	Surveys
EL_1	Households	Kitchen diaries
ES_1	Manufacturing	Surveys
	Households	Kitchen diaries
ES_2	Households	Kitchen diaries
FI_3	Households	Kitchen diaries
HU_2	Households	Kitchen diaries
IT_1	Manufacturing, households	Literature/proxy data
LV_2	Households	Surveys
NL_3	Households	Surveys
NL_4	Households	Mobile App
NO_1	Manufacturing, households	Surveys
	Retail	Records
PL_1*	Retail	Records
PT_1	Households	Surveys
PT_2**	Food services	Weighing
UK_1	Households	Kitchen diaries

* case study (one retailer)
** case study (one hospital)

3.7 Additional indicators

Some of the studies, besides quantifying the amount of food waste, have provided other indicators, mainly economic and environmental, linked to food waste. This section identifies which were those studies and what information was provided.

3.7.1 Economic indicators

Studies providing economic losses associated with food waste are the following:

- FR_1 has estimated the market value of the food waste quantified in their study to be €16 billion, representing a loss of €240 per person per year for the total FSC and €108 per person per year at consumption stage. This value was calculated using the selling price of the goods wasted at each stage. It does not include potential gains from the production of animal feed, energy (biogas) or compost, neither the direct cost (investment, human time to implement reduction measures, communication) or indirect costs (loss of activity for a market sector, for example) of prevention actions.
- LV_1 calculated a total average household loss of about €476 per year while LV_2 estimated an average loss of €87 per person per year associated with food waste. Both studies accounted for household food waste.
- AT_1 estimated that the value of the avoidable food (excluding food loss during kitchen preparation) wasted by the hospitality sector in Austria, is equal to €395 million per year. AT_2 calculated that, at retail and distribution, the value associated with the unsold and returned food amounted was about €255 million.
- PL_1 estimates that the economic losses due to food wasted by one supermarket over two weeks were equal to €5,500.
- PT_2 estimated that the food waste has a cost of €35.3 million per year in all hospitals in Portugal, equal to 0.5% of the Portuguese National Health budget.
- FI_3 reported that the value of food waste is approximately €150-220 per household per year. At the national level, Finnish households annually discard food with a value of €400-550 million.
- UK_1 estimated that the total value of the food wasted in the UK in 2015 was £20 billion (£307 per person per year). Of this amount, £14.9 billion per year (equal to £229 per person per year) were wasted at household level, £0.8 billion per year at retail level, 1.4 billion per year by the manufacturing sector, and £2.9 billion per year by the hospitality and food service sector.
- NO_1 reported the financial loss linked to food waste by stage of the value chain from 2010 to 2016. In 2016, food waste caused a financial loss of €731 million (6% less than in 2010). Of this amount, €283 million were lost by the retail sector, €15 million the wholesale sector, and €435 million by the food manufacturing sector. NO_2 estimated that the food waste generated by households corresponded to approximately €275 per person per year.
- According to EE_3, the monetary value of unsold food items in retail stores in Estonia can be estimated as €22 million per year.

Significant economic losses linked to food waste were reported by the studies analysed, with values ranging from approximately €90 to €275 per person per year. These values are also related to the cost of food in the country where the food is wasted. Another component that can influence the values estimated is the cost associated with the food waste treatment. The need to include this economic burden when assessing economic impacts of food waste was highlighted in study FI_3. Moreover, according to FI_2, a more comprehensive approach considering the entire production chain is needed to gain a holistic view of the economic losses caused by food waste.

3.7.2 Environmental Indicators

Some studies included an analysis the environmental impacts of food waste, mainly in terms of GHG emissions reported in CO_2 equivalents (CO_{2eq}).

- DK_2 performed the assessment of the environmental impacts of food waste using the Life Cycle Assessment tool EASETECH (Clavreul et al., 2014), considering several impact categories. The report shows that the prevention of a tonne of food waste may save 2,300 kg CO_{2eq} at the wholesale & retail sector, and 4,300 kg CO_{2eq} at household level.
- DE_1 assessed the environmental impacts of food consumption and food waste in Germany, using the impact assessment method ReCiPe Midpoint (Goedkoop et al., 2009). Several impact categories were analysed as well as the use of agricultural land and water for food production. The analysis shows that each year due to German food consumption 2.7 tonnes of CO_{2eq} per person are released, 14 m^3 of blue water per person are used for agricultural production, and 2,673 m^2 of agricultural land per person are occupied. Of these quantities, between 14% and 20% are related to food waste.
- EL_1 estimated the GHG emissions associated with food waste generation in Greece, by using CO_{2eq} emission factors for most of the food items retrieved from the Barilla database (Barilla, 2010). In this database, most of the GHG data is taken from the Ecoinvent database, the Danish food LCA database[8] and the Environmental Product Declaration system[9], and from Wallén et al. (2004). The results of this study show that 78 kg of CO_{2eq} per capita are associated with food waste up to the household stage. Avoidable food waste in Greek households is responsible for about 44 kg of CO_{2eq} per capita. In absolute terms, embedded GHG emissions in avoidable food wasted up to the household level were estimated as 881 Gg CO_{2eq} per year (15.5%), while GHG emissions embedded in avoidable food waste generated by households were estimated as 496 Gg CO_{2eq} year (8.7%). Finally, GHG emissions from food waste management were estimated as 4295 Gg CO_{2eq} per year (75.8%).
- FR_1 estimated the carbon impact of food losses and waste as 15.3 million tonnes of CO_{2eq}.
- According to the Natural Resources Institute of Finland, the GHG emissions of the food waste generated in one year along the food chain were equivalent to the annual emissions of about 400,000 passenger cars (FI_2). Study FI_3 estimated that the total GHG emissions caused by food waste were approximately 1,000 million kg of CO_{2eq} per year of which 36%, approximately 350 million kg of CO_{2eq} per year, was attributed to the food waste generated by households.
- NO_1 estimated that 412,300 tons of CO_{2eq} in 2016 (11% lower compared to 2010) were linked to the production, packaging and transport of food that was wasted. Of that amount, 120,785 tons of CO_{2eq} (29%) were linked to food wasted at retail level, 5,875 tons of CO_{2eq} (1%) at wholesale, and, 285,641 tons of CO_{2eq} (70%) at the industry. NO_2 estimated that the generation of food waste in Norway is responsible for 118 kg CO_{2eq} per person per year, equal to 615,600 tonnes CO_{2eq} per year, which corresponds to approximately 10% of emissions from passenger car transport in Norway (2016). The impact on climate change associated with food waste was calculated using LCA according to ISO 14040/44, European Commission JRC (2010) and European Commission JRC (2011).
- PT_2 estimated that about 16 thousand tonnes of CO_{2eq} are linked to food waste in all hospitals in Portugal.

[8] http://www.lcafood.dk/
[9] https://www.environdec.com/

The environmental impacts caused by food waste are significant and a system perspective should be considered to comprehensively assess such impacts. Therefore, both the environmental impact embedded in the wasted food items, calculated considering their full life cycle, and the environmental impact of the food waste treatment should be accounted for.

3.7.3 Social indicators

Only a few studies included the analysis of social indicators, namely the amount of food donated.

- According to BE_1, in 2015, a total of around 16,400 tonnes of surplus food was given a social purpose in Flanders. This involves the total of identified food surpluses given a social purpose in the sectors of producer organisations (auctions, 1,477 tonnes), food industry (12,599 tonnes) and retail (2,356 tonnes). According to the study, the figures reported are underestimated, since not all food surpluses that were given a social destination could be accounted for. This is mainly because there is a lack of structural monitoring and reporting among actors on both the supply and the demand side (social organisations).
- PL_1 stated that that two-thirds of the total food wasted at retail could be redistributed. The remaining amount could not be consumed for food safety reasons.
- A recent study reported in FR_1, led by an organization dedicated to waste prevention and sustainable energy for ADEME, showed that food donations could increase substantially in France. This study shows, for example, that retailers donate only 20% of dairy products.

The redistribution of food surpluses can have a significant impact in the reduction of food waste and bring social benefits such as providing meals to people in need that would otherwise not have access to food. According to what was reported in some of the studies analysed, there is still a lot of potential to increase the amounts of food donated, especially in the retail and distribution sector.

3.8 Gaps and challenges reported in the studies analysed

This section presents the main gaps and challenges reported in the studies analysed related with the elements of the delegated act. These aspects are critical for a robust and comprehensive quantification of food waste and include: (1) the food waste related definitions used, (2) the quantification/measurement methods used, and (3) the lack of data on food waste.

3.8.1 Distinction between edible and inedible parts of food

Separately reporting edible and inedible components of food waste can be particularly challenging at the manufacturing stage, where the boundaries between food and its associated inedible parts are not always clear-cut, as reported in study LU_1. SI_2 emphasized that the share of edible and inedible parts of food waste is a result of observations and assumptions, and not actual measurements. In the future, it will be necessary to further analyse and harmonise this distinction, because when it comes to reducing the amounts of food waste edible parts are more valuable and their reduction should be prioritized. The difficulty in estimating the share of edible/inedible parts was also mentioned by UK_1, where, due to the lack of data, there was no reliable breakdown between edible and inedible food waste for all the stages of the food supply chain, with the exception of households. To make sure food waste amounts are reported in a harmonised and comparable way, study SI_2 stressed the need for uniform guidelines of waste codes at national and international level (e.g. waste from the dairy production industry).

3.8.2 Measurement methods

Most of the studies analysed quantified food waste via surveys. In some cases this was the only method used, while in others it was used in combination with other methods. However, it has been observed that this measurement method can lead to a significant underestimation of the level of food waste (van Herpen et al., 2019). According to HU_2, respondents usually give generic, socially acceptable answers even in anonymous questionnaires. Therefore, conclusions will most likely be distorted in a positive direction (i.e. lower levels of food waste). Furthermore, according to HU_2, there is a risk of underestimating the levels of food waste generated also when data is collected with diaries. In this case, asking consumers to record the quantities of food waste generated in a logbook could also lead to misleading conclusions, because household members might be more conscious about shopping and eating in the test period(HU_2). The use of waste composition analysis enables objective measurement of food waste, but as stated by FI_3, it does not allow to assess the reasons behind the disposal of food. Furthermore, it does not capture several waste streams such as food fed to pets, home composted, and disposed through the sink and toilet. For these reasons, ideally composition analyses should be complemented by diaries, which enable to investigate the drivers of food waste generation. Furthermore, by collecting background data on socio-demographics, behaviour and attitudes of the participants, it is possible to perform statistical analysis to better understand the influence of these factors on the generation of food waste by different groups of households.

3.8.3 Lack of data

The lack of data is the aspect most often mentioned in the different studies analysed and can be due to:

(1) Scarcity of food waste accounting exercises (in particular at primary production);

(2) Unwillingness of food business operators to provide food waste data related to their activities, recorded at the processing and manufacturing and retail and distribution stages;

(3) Lack of representative data (mainly due to small and unrepresentative samples used in the studies), reported mainly at the consumption stage.

Difficulties in collecting information on food waste in the primary production sector were highlighted in studies LU_1, FI_3, SI_2, and UK_1. These included methodological challenges such as measuring the unharvested food commodities left on the field (LU_1). Furthermore, within the production sector, NO_1 mentioned the lack of information in the fish production.

The lack of information in the processing and manufacturing sector was emphasized by DE_2 and NO_1. According to DE_2, one of the main reasons for this is the fact that neither industries nor public entities are obliged to report the food waste generated. For this reason, no reliable statistical data can be found and, therefore, food waste amounts are based on figures from the literature and collected using methods that are not completely reliable. Another reason provided by EE_2 is the fact that there was no incentive for manufacturers to respond to surveys because they do not see this as a benefit for their business.

The difficulty in collecting data and information at retail and distribution stage was pointed out by DE_2, AT_2, and LU_1, highlighting that it was quite challenging to draw conclusions on the situation in the whole sector. PL_1 emphasizes the necessity of conducting research on food waste in the retailing sector at national level, including larger sample size, longer periods for data collection, and additional information such as the main causes for food wastage. Despite the fact that NO_1 obtained reliable data for this sector, it reported some difficulties in setting the boundaries between wholesalers and transport companies, because the latter are not part of the wholesale companies but food waste can be generated in their vehicles.

Regarding restaurants and food services, studies DE_2 and LU_1, mentioned difficulties in extrapolating the results obtained to the entire country. LU_1 states that one of the reasons for such difficulties is related to the small number of samples and the short period in which information on the food waste generated was collected.

In general, one of the main difficulties found, common to all the sectors above mentioned, is the sharing of food waste data. According to CZ_2, the different actors of the FSC are often reluctant to share data. CZ_3 explained that despite data exists in some stages such as the retail sector, the businesses do not want to provide this information as it is considered sensitive. This was also pointed out by FR_1, showing that manufacturers and distributors have access to the most accurate information in this area but they are rarely willing to provide data because they consider it confidential. Additionally, the disclosure of this information could jeopardize the competitiveness of the company or lead to 'malicious communications'. Furthermore, FR_1 introduced the lack of awareness as one of the relevant factors for the scarcity of information on food waste. This lack of awareness covers the main actors of the FSC, both upstream (farmers and food manufacturers) and downstream (including restaurants, caterings, distributors, households). Generally, actors have a vague idea of what they are losing and wasting and only a few of them have established methods for the evaluation of food waste.

More data is available on food waste generated in households compared to the other stages of the FSC; however the current data might not be of good quality (e.g. underestimating food waste due to biases in the measurement method) or not representative of the country considered. This aspect was mentioned by HU_2, where it was stated that the reported results might be biased due to: (i) missing income profiles in the sample of households considered and (ii) the time of the year when the data was collected. A similar situation was found in FI_3 as the sample used was not representative of the studied population and it did not cover the entire territory of the country. Thus, according to EL_1, solving these aspects are crucial because the food waste generation by households have a high variability that depends on several factors such as the family structure, its eating and consumption habits, the variability of the seasons and special holidays.

As explained in HU_2, research should be carried out with larger sample sizes and ensuring the representativeness of the population. A larger sample size would allow the use of cluster analysis to identify the most relevant consumer categories as 'target groups', which could be an important input for decision makers to formulate an effective policy for food waste prevention in households. Analysis techniques such as Structural Equation Modelling considering attitude and behaviour parameters could be used to identify direct or indirect influence of different factors in the generation of waste.

4 Discussion

This review highlights the scarcity of studies quantifying food waste generated along the FSC at MS level and the lack of a harmonized approach for food waste quantification. Countries for which no study at national level was found are Belgium (although several studies for Flanders are available), Bulgaria, Cyprus, Ireland, Lithuania, and Poland. Similarly to what was observed in other studies (Corrado & Sala 2018, Roodhuyzen et al. 2017, Caldeira et al. 2017), different food waste definitions were used in the studies analysed. Although the FUSIONS project has published guidelines providing a clear definition of food waste, only 6 out of 48 studies analysed have explicitly adopted it. Similarly, very few studies followed the guidance provided in the FLW standard. Although this standard does not provide a unique definition of food waste, it provides guidance to conduct food waste quantification studies. The use of a common food waste definition is critical for the comparison of studies between countries and to evaluate the performance of countries towards target SDG 12.3.

In combination with a common food waste definition, the other important aspect to ensure comparability of studies is to guarantee a clear identification of the geographical and temporal scope and the system boundaries of the study. This entails to explicitly state which stages of the FSC are included in the assessment, and which specific activities are considered within each stage (e.g. restaurants, hotels, public caterers). Although for a number of countries, studies covering the full FSC were available, their comparison is not straightforward as they adopted different definitions of food waste (e.g. some considered only edible parts and others both edible and inedible, for some food diverted to animal feed was not accounted as food waste, and for others it was). The same was observed for studies covering different stages of the FSC within the same MS. Therefore, it is not possible to combine the studies covering different stages of the FSC to provide a full picture of food waste quantification within one country.

Different measurement methods were used and, in most cases, there was a combination of methods used within the same study. The direct method most used was surveys, mainly to measure household food waste. As pointed out by van Herpen et al. (2019) care should be taken when using this method as figures obtained from general survey questions appear to be less valid, leading to large underestimation of the levels of food waste. Although waste composition analysis would provide data that are more accurate, this method was only used in 8 studies to account for food waste at the household stage. Nevertheless, it should be noted that when such method is adopted, food waste disposed via the sewer and home composted is not quantified. In order to capture these two waste streams at household level the most reliable method is to use kitchen diaries. Another direct method frequently used to quantify food waste generated at the retailing stage was records (e.g. by using sales data to identify unsold items, which were disposed of). Among the indirect methods, the most used were literature data and proxy data.

A large variability in the amounts of food waste reported by the different studies was observed. Such differences are mainly due to different accounting approaches adopted e.g. the definition of food waste adopted, the scope of the study and system boundaries selected. None of the studies have considered the embedded food waste associated with traded goods within the scope of their study, while two of the studies analysed have excluded food waste associated with exported goods.

The destinations of food waste varied significantly across studies, countries, and stages of the FSC. In some cases (e.g. Flanders region, the Netherlands, Slovenia) a significant part of the food waste is valorised either as animal feed, for composting, or anaerobic digestion. The valorisation of horticultural waste for alcohol production was reported as a common practice in Italy and the Netherlands. Finally, home composting and/or feeding food waste to pets was reported by studies conducted in Hungary, the Flanders, Sweden, and the UK. Nevertheless, one should keep in mind that according to the EU definition of food waste, these flows i.e. food that instead of being wasted is valorised as animal feed are not considered food waste and are, therefore, out of the scope of the delegated act.

Regarding the measurement of liquid food waste, 22 of the studies analysed have accounted for it separately, attributing this to specific food categories, such as milk or beverages in general. This measurement was done using either surveys or kitchen diaries. As mentioned above, the former method may provide inaccurate information as people tend to provide socially-acceptable answers, underestimating the amounts of food waste they generate, while the latter may be more reliable. There is little information on which method should be used to properly capture this fraction of food waste. Only recently guidelines were published by WRAP (2019), to support business in the quantification of food waste discharged to the sewer/wastewater treatment as part of sludge generated from on-site treatment of effluent.

Some studies have reported economic and environmental indicators linked to the food waste estimated. Economic losses were calculated considering the value of food at the stage were the food was wasted and in some cases, considering the cost of the food waste treatment. The environmental impacts were mostly reported in terms of GHG emissions, calculated using LCA. The consideration of these additional indicators is relevant to provide a comprehensive picture on the consequences of wasting food and raise awareness on the inefficiencies of the FSC. These indicators should be calculated adopting a system thinking perspective, capturing all the burdens associated with food waste.

The most critical challenge identified in the studies refers to the lack of good quality data encountered at all the stages of the FSC. This can be attributed to (1) the scarcity of food waste accounting exercises; (2) the unwillingness of entities, in particular businesses, in sharing their data because they do not see it as a positive aspect and they fear that the disclosure of such information may jeopardize their competitiveness; and (3) the unrepresentativeness of the data. Other challenges identified were the difficulty in distinguishing between edible and inedible parts of food, and the risk of underestimating food waste with some measurement methods.

5 Conclusions

From the review herein presented, one can conclude that there is a dearth of studies accounting for food waste in the MSs considering the entire FSC and only a few have referred to the use of guidelines for food waste quantification such as the FUSIONS or the FLW Standard. In light of what is required in the delegated act, MSs still have to improve their food waste accounting. An essential aspect is to develop studies using the food waste definition considered in the delegated act, which is in line with the FUSIONS definition and consistent with the FLW Standard. Such definition includes the quantification of both edible and inedible parts of food. Regarding the coverage of the FSC, only 10 MSs have quantified food waste along the entire FSC. This is another aspect to be improved towards the compliance with the delegated act requirements.

The comparison of the quantities of food waste reported in the studies is very limited. In fact, the figures reported may be different due to variability among countries in terms of food waste generation profiles as well as due to the use of different food waste definitions, and system boundaries. Moreover, the use of different measurement methods may influence significantly the results and their comparison. The majority of the data reported was collected either using direct methods such as surveys, or from indirect sources such as literature or proxy data. These quantification methods are not the most adequate to provide a comprehensive and precise picture of food waste generation. Data obtained from surveys can be very often underestimated and such indirect sources of information often provide inaccurate or incomplete data. Therefore, methods that are more accurate should be used (e.g. direct weighing or waste composition analysis). Additionally, as required in Article 4 of the delegated act, it is very important that MSs ensure the reliability and accuracy of the measurements of the food waste, ensuring the representativeness of the samples used and reflecting on the variations observed in the data, being aware that socio-demographic factors may also influence results. These aspects were barely addressed in most of the studies analysed.

To sum up, MSs need to develop studies providing reliable and comparable data on food waste quantification. Although some MSs have already been developing work in this area, others have not yet conducted any study quantifying food waste. This discrepancy on the state of play on food waste quantification among the different MSs is a big challenge. The delegated act is expected to contribute to its resolution by providing a common approach for MSs to develop their studies. Nevertheless, since the delegated act provides flexibility in terms of which measurement methods to use, it is crucial that clear information is provided on the procedures and assumptions taken, pointing out potential sources of uncertainty. This, together with a common definition of food waste and a harmonized quantification approach will definitely contribute to ensure comparability of studies among countries and enable to assess their performance towards the SDG target 12. 3.

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List of abbreviations

ADEME	French agency for environment and energy management
BVE	Federation of German Food and Drink Industries
CO_2 eq	Carbon dioxide equivalent
DG	Directorate General
EC	European Commission
EU	European Union
EWC	European Waste Classification
FLW	Food Losses and Waste
FSC	Food supply chain
GHG	Greenhouse Gas
HoReCa	Hotel - Restaurant - Café
JRC	Joint Research Center
FSC	Food supply chain
LCA	Life Cycle Assessment
LoW	List of Wastes
MS	Members State
NGO	Non-Governmental Organization
OVAM	Public Waste Agency of Flanders
PP	Primary Production
P&M	Processing and Manufacturing
RD	Retail and Distribution
RFS	Restaurants and food services
SDG	Sustainable Development Goal
WRAP	Waste and Resources Action Programme
WCA	Waste composition analysis

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Annex 1. Food waste quantification in additional studies

Table 13. Food waste quantified in the studies carried out by Bräutigam et al. (2014), and Monier et al (2010).

	Bräutigam et al. (2014)		Monier et al (2010)	
Country	**Total figures (1.000 tonnes)**	**Kg per capita**	**Total figures (1.000 tonnes)**	**Kg per capita**
AT	2,276	275	1,858	225
BE	3,222	304	4,192	399
BG	1,638	215	674	87
CY	256	245	256	334
CZ	1,941	189	729	71
DE	18,671	223	10,387	125
DK	1,868	343	642	118
EE	303	230	355	264
EL	4,838	438	488	44
ES	16,494	374	7,696	176
FI	1,196	227	1,013	192
FR	18,500	299	9,078	144
HR				
HU	2,723	270	1,858	184
IE	1,189	281	1,051	250
IT	19,696	333	8,778	149
LT	881	272	581	171
LU	101	217	97	205
LV	572	261	216	94
MT	102	245	25	63
NL	6,495	397	9,456	580
PL	12,116	317	8,972	235
PT	3,238	307	1,391	131
RO	7,261	329	2,274	105
SE	2,075	228	2,053	226
SI	473	236	179	90
SK	943	175	589	109
UK	13,669	225	14,391	280

Table 14. Food waste reported in FUSIONS (2016) as total amount and in kg per capita (in brackets).

Country	Production tonnes (Kg per capita)	Processing tonnes (Kg per capita)	Food service tonnes (Kg per capita)	Wholesale and retail tonnes (Kg per capita)			Households tonnes (Kg per capita)
				Wholesale	Retail	Wholesale + Retail	
AT			280,000 (22)		74,100 (9)		369,000 (45)
BE				5,200 (0.5)	167,100 (16)	172,300 (16)	
BG							
CY							
CZ							
DE	1,186,244 (14)	1,850,000 (22)	1,900,000 (23)	60,000 (1)	490,000 (6)	550,000 (7)	5,050,000 (61)
DK	169,000 (31)		115,700 (21)				462,774 (85)
EE						6,270 (5)	70,000 (52)
EL						79,718 (7)	
ES							
FI	63,000 (12)		130,000 (25)				345,000 (66)
FR	1,990,063 (31)	626,000 (10)	1,080,000 (17)				
HR							
HU							
IE			258,900 (62)				251,000 (60)
IT	1,246,603 (21)			118,317 (2)	270,776 (5)	389,093 (7)	
LT		105,870 (31)					
LU				595 (1)	2,099 (4)	2,694 (6)	42,374 (90)
LV							
MT							54,604 (135)
NL					18,000 (1)		1,119,199 (69)
PL							
PT							
RO							
SE	111,000 (12)		200,000 (22)		69,676 (8)		683,529 (76)
SI							
SK							
UK		3,900,000 (65)	920,000 (15)	17,297 (0.3)	403,500 (7)	420,797 (7)	4,670,000 (77)

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