Food waste measurement toward a fair, healthy and environmental-friendly food system: a critical review

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Received 28 July 2020
Revised 8 September 2020
Accepted 3 October 2020

Abstract

Purpose – Given the importance of food waste in the economic, social, health and environmental dimensions, the purpose of this work is to detect, through a systematic and configurative literature review on food-waste-measurement methodologies, the global approaches, characteristics, limitations, opportunities and results applied within the literature. The analysis of these papers provides useful information about how far we are from international action plans and, therefore, how we need to direct programs and policies to measure and reduce food waste and ensure food security and food safety.

Design/methodology/approach – The authors have conducted a systematic, configurative literature review on food waste measurement methodologies applied only within empirical studies published in academic peer-reviewed scientific journals. Based on the Commission Delegated Decision (EU) 2019/1597 of May 3, 2019 (OJEU, 2019) regarding common methodologies and minimum quality requirements for the homogeneous assessment of food waste quantities and composition, the authors investigated the issue on Web of Science Core Collection (WoS) from June 2000 to June 2020. The authors researched keywords within article titles, abstracts and author keywords by utilizing 34 different research strings.

Findings – The proposed review particularly refers to following topics: measurement methodologies applied according to the Commission Delegated Decision (EU) 2019/1597; editorial placement and publication timeline; geographical area; food supply-chain stage and publication journals; and the main features, limitations, opportunities and results for each measurement methodology as presented by authors. Among the first 48,000 results, only 58 academic articles are perfectly in line with the aim of the review, highlighting the lack of standardized methodologies, the limits of those proposed and the deficiency of comparable results to achieve sustainable international goals.

Originality/value – The proposed review is one of the few concerning food waste measurement methodologies. Food waste measurement is essential to rebalance the actual inadequate food system and to switch it toward a fair, healthy and environmentally friendly one, thereby (1) managing the human nutrition system paradox of hungry, undernourished and over-weight people; (2) reducing food insecurity; (3) ensuring each living being's access to healthy, nutritious and sustainable food; and (4) reducing environmental impacts (neutral or positive impact) and the loss of biodiversity and mitigating climate change.

Keywords Food waste, Food safety, Food security, Food waste measurement, Nutritional security

Paper type Literature review

1. Introduction

Food loss and food waste represent global health, social, economic and environmental concerns, imposing several challenges in terms of sustainable development (Costello *et al.*, 2015), waste management (Cristòbal *et al.*, 2018), human health (Vandevijvere *et al.*, 2015; Salemdeeb *et al.*, 2017) and reduction in financial operating costs (Dreyer *et al.*, 2019). The importance of food loss and food waste has increased over the last few decades

British Food Journal
Vol. 123 No. 8, 2021
pp. 2907-2935
Emerald Publishing Limited
0007-070X
DOI 10.1108/BFJ-07-2020-0658

(Gustavsson *et al.*, 2011; Corrado *et al.*, 2019) and was included within the United Nations 2015 Sustainable Development Goals (SDGs), with particular reference to zero hunger (SDG 2) and responsible consumption and production (SDG 12). By 2030, humans must "halve per capita global food waste at retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (FAO, 2020a). Furthermore, to achieve such aims, the European Commission (2015) enacted the "Closing the loop – An EU action plan for the Circular Economy." The action plan was later implemented by the introduction of the monitoring framework for the circular economy (European Commission, 2018), where food waste is explicitly mentioned as one of the 10 circular economy indicators (Moraga *et al.*, 2019; Eurostat, 2020). A main objective of the European Green Deal is the Farm to Fork Strategy, which aims to create a fair, healthy and environmentally friendly food system by reducing environmental impacts, mitigating climate change, reversing biodiversity loss and pursuing food security, nutrition and public health, thereby ensuring access to healthy, nutritious and sustainable food (European Commission, 2020). As part of the Farm to Fork Strategy, sustainable food consumption and food loss and waste prevention are essential because reducing food waste brings savings for consumers and operators, and the recovery and redistribution of food surplus could lead to the generation of nutrients, feed and secondary raw materials (European Union, 2020).

Each year, more than 1.3 billion tons (*t*) of food are thrown away along the entire food supply chain worldwide – equal to roughly one-third of the global food production for human consumption and more than one-quarter of the global agricultural production (Gustavsson *et al.*, 2011; FAO, 2013; International Food Policy Research Institute, 2019). In developed countries (1.4 billion people), 670 million tons (Mt) of food is discarded, and less than 630 Mt is discarded in developing countries (6.2 billion people). On average, it is estimated that approximately 11–23% of food waste occurs at the agricultural stage, 17–19% during industrial processing, 8–17% at the retail stage and more than 50% at final consumption, which considers the hospitality sector and households (FAO, 2017; 2019a, b). Wide differences occur between regions of the world. For instance, North America and Oceania waste more than 110 kg/capita at final consumption yearly, but sub-Saharan Africa wastes less than 10 kg/capita (Bräutigam *et al.*, 2014; Hodges *et al.*, 2010; Pellegrini *et al.*, 2019; Philippidis *et al.*, 2019). In particular, the European Union's food waste amounts to approximately 130 Mt per year, of which more than 24% is at primary production, 23% is during processing and manufacturing, 5% is at the retail level, 39% is at the household level and 9% is from hospitality industry (Caldeira *et al.*, 2019). In terms of nutritional values, it is estimated that, in Europe, each year less than 520 million MJ are lost, useful to satisfy the energy intake (2,400–3,100 MJ/year) of about a third of the current European population (Gustavsson *et al.*, 2011; Beretta *et al.*, 2013; Fiore *et al.*, 2015; Britz *et al.*, 2019; Caldeira *et al.*, 2019; FAO, 2020b; Istat, 2020).

Currently, it is not possible to talk about healthy nutritional systems, food safety and food security, which is achieved when "all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996), without *rebalancing* the inadequate food system toward a fair, healthy and environmentally friendly one. In this field, food waste measurement represents a daunting and key factor. Divergent definitions, scarce data and unstandardized methodologies complicate the field's assessments. Given the importance of food waste in the economic, social, health and environmental dimensions, the purpose of this work is to detect, through a systematic and configurative literature review on food waste measurement methodologies, the global approaches, characteristics, limitations, opportunities and results applied within the literature. The analysis of these papers provides useful information about how far we are from international action plans and how we need to direct the programs and policies to measure and reduce food waste and ensure food security and food safety.

2. Research method

The authors have conducted a systematic, configurative literature review on the food waste measurement methodologies applied within empirical studies. The starting point was the Commission Delegated Decision (EU) 2019/1597 of May 3, 2019 (OJEU, 2019), which supplemented the Directive 2008/98/EC, regarding common methodologies and minimum quality requirements for the homogeneous assessment of food waste quantities and composition. The decision identified the following as common methodologies: diaries, direct measurements, questionnaires, surveys and interviews (generally applied as synonyms), mass balances and waste composition analyses. Methods based on direct access to food waste, which are used by an entity with physical access to food waste, should be distinguished from other methods, which cannot be based on physical access and with which direct measurement is not feasible.

The first step in conducting a systematic literature review, as stated by Sassanelli *et al.* (2019) and Özbük and Coşkun (2020), is the identification of the research question and the assumption of inclusion and exclusion criteria. Subsequently, the authors selected an adequate database and research strings related to the food waste issue and then collected and synthesized the data. Moreover, articles selected on existing knowledge, experts' recommendations and serendipity have been added to the analysis.

Although some studies apply mixed methodologies to analyze food waste issue in general (e.g. causes, drivers, and solutions), the present paper investigates only those that measure, quantify or evaluate food waste streams in particular. Thus, the following paragraphs focus only on food waste measurement instead of analyzing other methodologies inspecting consumer behavior, purchase frequency or other qualitative information.

2.1 Research questions, general assumptions and review criteria

As previously stated, a plethora of studies – among the most cited being Parfitt *et al.* (2010), Buzby and Hyman (2012) and Beretta *et al.* (2013) – have been conducted on food waste worldwide, focusing on its main causes (Mena *et al.*, 2011; Aschemann-Witzel *et al.*, 2015; Boschini *et al.*, 2020), related opportunities for its reduction (Priefer *et al.*, 2016) and its valorization (Mirabella *et al.*, 2014; Kim *et al.*, 2020), from primary production (Baker *et al.*, 2019; Schneider *et al.*, 2019) to processing and manufacturing (Flores *et al.*, 1999; Loke and Leung, 2015), retail and distribution (Lebersorger and Schneider, 2014; Goodmann-Smith *et al.*, 2020), the hospitality industry (Papargyropoulou *et al.*, 2016; Wang *et al.*, 2017; Giboreau *et al.*, 2019) and households (Graham-Rowe *et al.*, 2014; Fiore *et al.*, 2017; Slorach *et al.*, 2020). However, the main critical issues related to food loss and food waste concern their various and divergent definitions, sparse data collection – considering the uncertainty embedded in primary and secondary data (Corrado *et al.*, 2019) – and their complicated quantification and qualification (composition). To this extent, based on international reports (Møller *et al.*, 2014; Tostivint *et al.*, 2016), the authors try to answer to the following questions:

- *RQ1.* What is the publication timeline, geographical area, food supply chain stage and publishing journals?
- *RQ2.* In the analyzed papers, how are measurement methodologies applied according to the Commission Delegated Decision (EU) 2019/1597 (OJEU, 2019)?
- *RQ3.* Which are the main features, limitations, opportunities and results for each measurement methodology?

Based on the FAO (2011), the authors have applied one of the most common definitions of food loss and waste: "the masses of food lost or wasted in the part of food chains leading to edible products going to human consumption." This means that food originally intended for human consumption but later excluded from human nutrition should be considered as waste,

even if reused for other purposes (e.g. energy recovery). However, food loss mainly occurs in agricultural production, the post-harvest period, manufacturing and retail (upstream stages), while food waste takes place in the hospitality industry (canteens, restaurants, hotels) and households (downstream stages) (Amicarelli *et al.*, 2020).

The authors only reviewed academic peer-reviewed journal articles, to investigate studies making explicit references to measurement methodologies. Therefore, irrelevant articles have not been included (e.g. articles on food waste valorization and/or recovery), nor have books, books chapters, conference papers, review articles and papers written in other languages than English.

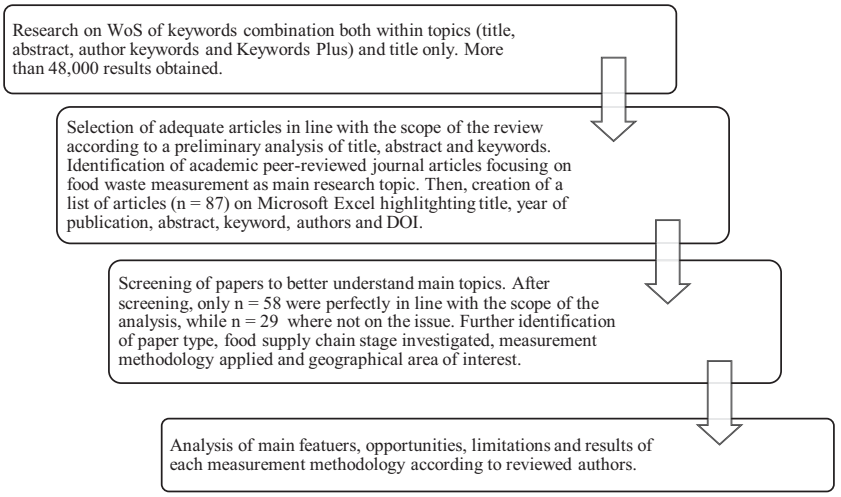
2.2 Database and research strings

The analysis was conducted on Web of Science Core Collection (WoS), which is one of the world's most trusted citation indexes for scientific and scholarly research. It includes more than 21,000 journals, 76 million records, 111,000 books and roughly 8 million conference papers on life and natural sciences, biomedical and social sciences, engineering, arts and humanities (Clarivate, 2020). In line with Macke *et al.* (2018) and Wu *et al.* (2018), the authors rely on WoS since it guarantees standardized, reputable and high-quality publications and ensures the quality of papers analyzed.

The publication period was from June 2000 to June 2020, even though the first studies conducted in the United States (US) on food waste date back to 1974 (Hall *et al.*, 2009) and the first definition of waste was introduced in Europe in 1975 through Council Directive 75/442/EEC of 15 July 1975 on Waste (OJEC, 1975). Moreover, all geographical areas were considered. The starting point for the review was to identify (truncated) keywords used in combination with each other, to cover as many relevant items as possible. The keywords were "food waste," "food loss" AND "measure," "quantification," "quantity," "quantifying," "method," "methodology," "estimation," "assessment," "diaries," "direct measurement," "interview," "questionnaire," "survey," "mass balance," "material flow analysis" and "waste composition analysis," totaling 34 research strings. The research keywords were explored within the article titles, abstracts and author keywords. Subsequently, the authors selected the relevant studies and created a list of them in Microsoft Excel, including their title, year of publication, journal, paper type (e.g. review, research), investigated food supply chain stages, applied measurement methodologies, geographical area and digital object identifier (DOI), and duplication was avoided. Lastly, the selected articles on existing knowledge, expert recommendations and serendipity were added ($n = 8$). Figure 1 illustrates the research strategy, while *Supplementary Material* shows the final article database.

3. Timeline, journals and geographical area (RQ1)

Among the plethora of studies about food loss and waste, only 58 articles were selected due to having practical applications of one or more measurement methodologies for their quantification and qualification. Even though the publication period investigated was from June 2000 to June 2020, the earliest selected study was published in 2010, revealing that academic scientific research has been perfectly in line with studies conducted by national and international institutions. In 2011, the FAO published its first report assessing food loss and waste along the global food supply chain (Gustavsson *et al.*, 2011). No articles were selected from 2000 to 2009. Figure 2 shows the publication period, revealing that the highest proportions of articles were published between 2017 (16%) and 2019 (31%), probably as a consequence of the SDGs being introduced and the European monitoring framework for circular economy implementation. Moreover, 2019 recorded the highest interest for food waste measurement because the Commission Delegated Decision (EU) 2019/1597 was enacted year, while by June 2020 (mid-2020), eight articles have already been published (14%).

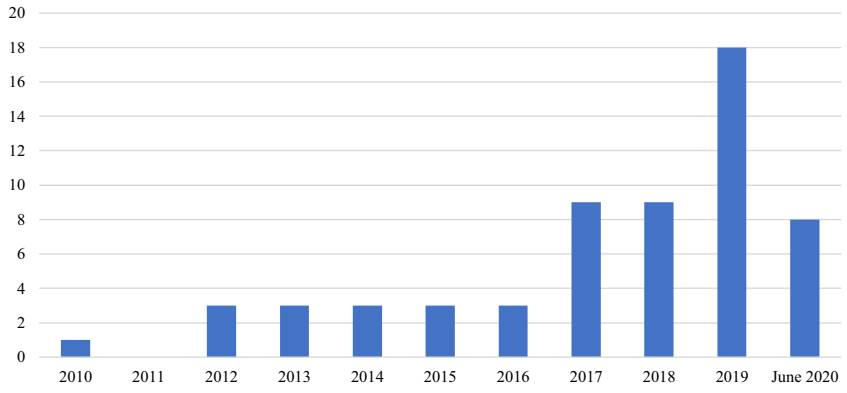


Source(s): Personal elaboration by the authors

Figure 1.
Research strategy

The authors only selected articles from academic peer-reviewed journals, even though some interesting contributions were available from proceedings of international conferences (Ganglbauer *et al.*, 2015; Le *et al.*, 2015; Mandasari, 2017). According to Figure 3, only eight journals have published more than two articles on food waste measurement applications. The majority were collected from *Waste Management* (13 articles, 22%); *Resources, Conservation and Recycling* (10 articles, 17%); and *Journal of Cleaner Production* (eight articles, 14%), followed by *British Food Journal* (five articles, 8%) and *Sustainability* (four articles, 7%).

The highest percentages of contributions involved detecting food waste in the US (10 articles) and Europe, specifically in Finland, Germany, Italy and Sweden (six articles each) as well as Austria, Netherlands, Norway and Switzerland (three articles each). The US states involved in food waste measurement were California, Colorado, Hawaii, Iowa, Missouri and North Carolina, with one contribution each. Figure 4 illustrates the countries



Source(s): Personal elaboration by the authors

Figure 2.
Publication timeline and historical trend by year (2010–2020)

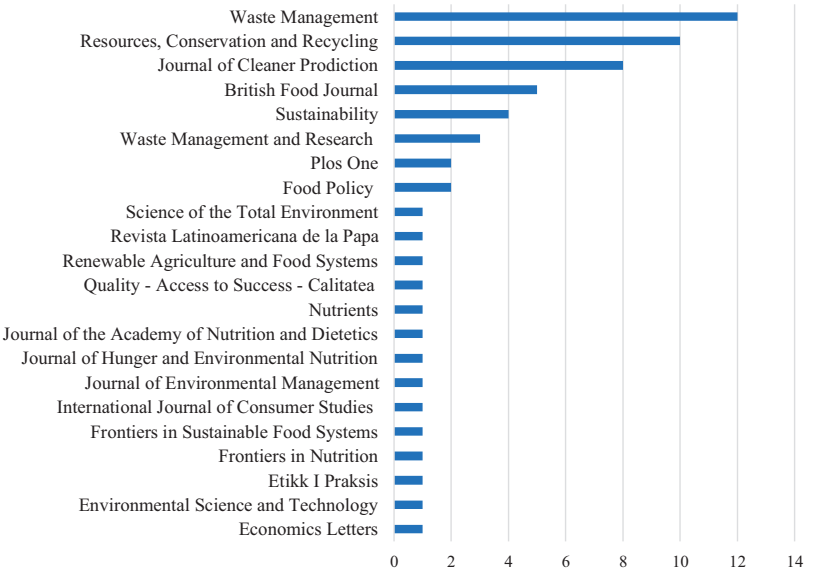


Figure 3.
Publishing journals

Source(s): Personal elaboration by the authors

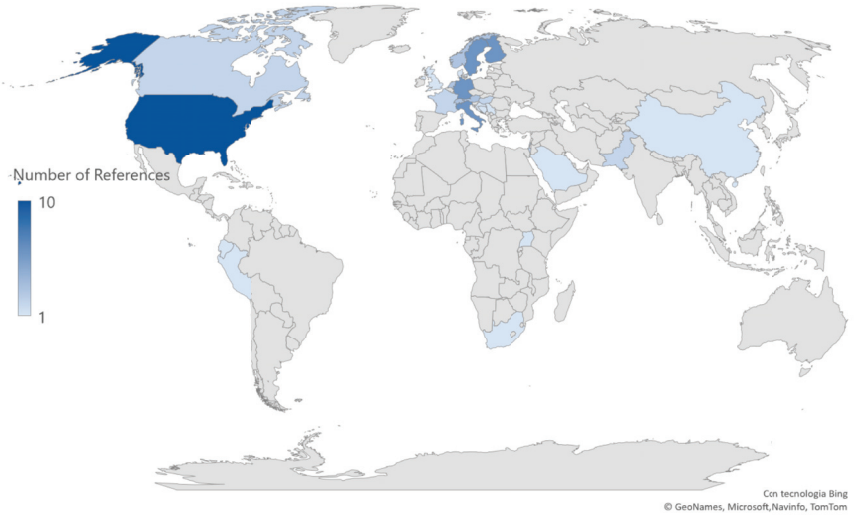


Figure 4.
Geographical areas covered by the selected contributions

Source(s): Personal elaboration by the authors

investigated, but note that in several cases (Gjerris and Gaiani, 2013; Hartikainen *et al.*, 2018; Malefors *et al.*, 2019), studies analyzed and/or compared more than one geographical area.

4. Food waste measurement methodologies: literature review (RQ2 and RQ3)

Before analyzing all of the measurement methodologies and describing the opportunities and limitations highlighted by all of the selected papers, Table 1 briefly presents the final set of 58 contributions per author, the measurement methodologies applied, and the food supply chain stages investigated. In general – and considering that several studies investigated more than one food supply stage at once – a majority of the authors investigated households (45%) and the hospitality industry (26%), including school and university canteens, hospitals, hotels, restaurants and elderly care homes. On the contrary, only a few studies have quantified food waste at upstream stages (from agricultural production to retail), with the highest percentage of authors analyzing on-farm and retail losses. Regarding measurement methodologies, some of the selected papers proposed existing methodologies (e.g. diaries, questionnaires), while some others applied a mix of them (e.g. direct measurements plus literature data, questionnaire plus waste composition analysis) or proposed variants of existing methodologies (e.g. liquid waste analysis, visual plate waste photographs, expenditure surveys). A majority of the authors applied questionnaires and surveys (43%), followed by direct measurement (e.g. of garbage streams or plate waste and with kitchen scales or measuring glasses) (37%) and diaries (19%). However, many studies appeal to the literature and company datasets to fill data gaps (22%), especially the authors who investigated the whole food supply chain, from the agricultural stage to final consumption (Buzby and Hyman, 2012; Kummu *et al.*, 2012; Beretta *et al.*, 2013; Caldeira *et al.*, 2019; Willersinn *et al.*, 2015).

4.1 Diaries

Among the methodologies presented by the Commission Delegated Decision (EU) 2019/1597, food diaries (also called kitchen diaries) generally refer to individuals or groups (e.g. families, cohabitants) living in a certain geographical area (e.g. provinces, regions or countries) who are asked to measure and self-report food waste occurring during their daily life (Møller *et al.*, 2014). In addition, people are invited to indicate waste-generation moments (e.g. preparation, leftovers), the main reasons for discarding the food and their disposal procedures (e.g. kitchen bins, home composting) (Quested *et al.*, 2020). Over the last decade, food diaries have been applied successfully in numerous studies worldwide, representing a useful tool in food waste research, although with several limitations. Table 2 illustrates the main findings from the selected articles ($n = 12$), including their design/methodology/approach, analysis period, sample size and brief results.

Generally, food diary participants seemed very enthusiastic about participate over the measurement period (Langeley *et al.*, 2010; Sharp *et al.*, 2010), but its application presents several difficulties and some disadvantages. First, a majority of the authors found it hard to recruit households and noticed high dropout rates during the experimental periods, with potential risks of self-selection – only interested people take part in the experiment – and poor data quality due to undervaluation and approximation. Moreover, if online-based food diaries are applied, the majority of aged people (60 years old or older) are unable to take part to the measurement. In addition, to adopt "more socially acceptable" behavior during the accounting period, participants tend to eat differently than normal or dispose food in more sustainable manners (Quested *et al.*, 2020), and diary keepers, in the absence of coaching, are usually not aware of the waste generated by their relatives/cohabitants or are confused during measurement. Lastly, people who take part in experiments are generally not representative of the entire population, and adjustments are sometimes extremely difficult and aleatory.

4.2 Direct measurement

Direct measurement comprises various methods such as direct counts and weight and/or volumetric assessment. Generally, it produces the most accurate data but has high cost, time

References	Food supply chain stage						Measurement methodologies				
	AG	PR	RE	HO	HOS	DI	DM	LCD	MB	QSI	WAC
Amato and Musella (2017)				X						X	
Amicarelli *et al.* (2020)	X	X						X	X		
Baker *et al.* (2019)	X									X	
Beretta and Hellweg (2019)				X			X	X			
Beretta *et al.* (2013)	X	X	X	X	X			X	X		
Boschini *et al.* (2018)				X			X				
Brancoli *et al.* (2017)			X				X				
Buzby and Hyman (2012)	X	X	X	X	X			X			
Caldeira *et al.* (2019)	X	X	X	X	X			X	X		
Chakona and Shackleton (2017)					X					X	
Costello *et al.* (2015)				X			X				
Delley and Brunner (2018)					X	X					X
Djekic *et al.* (2019)					X					X	
Elimelech *et al.* (2018)					X						X
Elimelech *et al.* (2019)					X					X	
Eriksson *et al.* (2012)			X				X	X			
Eriksson *et al.* (2017)				X			X				
Eriksson *et al.* (2020)				X						X	
Giboreau *et al.* (2019)				X			X				
Giordano *et al.* (2018)					X	X				X	X
Giordano *et al.* (2019a)					X	X					
Giordano *et al.* (2019b)					X	X				X	
Gjerris and Gaiani (2013)					X			X			
Goodmann-Smith *et al.* (2020)			X					X			
Hanssen *et al.* (2016)					X						X
Hartikainen *et al.* (2018)	X						X	X		X	
Ilakovac *et al.* (2020)					X	X					
Johnson *et al.* (2018)	X						X				
Kallbekken and Saelen (2013)				X			X				
Kasza *et al.* (2020)					X					X	
Katajajuuri *et al.* (2014)			X	X	X	X				X	
Khalid *et al.* (2019)					X		X				
Kummu *et al.* (2012)	X	X	X	X	X			X			
Langeley *et al.* (2010)					X	X					
Lebersorger and Schneider (2014)			X					X			
Leverenz *et al.* (2019)					X	X					
Loke and Leung (2015)	X	X	X					X			
Malefors *et al.* (2019)				X				X			
Moreno *et al.* (2020)					X	X					
Pflugh Prescott *et al.* (2019)				X			X			X	
Pirani and Arafat (2016)				X					X	X	
Rajan *et al.* (2017)				X							X
Redlingshofer *et al.* (2017)	X	X	X					X			
Richter and Bokelmann (2017)					X	X					
Schneider *et al.* (2019)	X						X				
Silvennoinen *et al.* (2014)					X	X					
Strotmann *et al.* (2017)				X			X				
Szabò-Bòdi *et al.* (2018)					X					X	
Thyberg *et al.* (2015)					X			X			
Tostivint *et al.* (2017)	X	X	X							X	
van der Werf *et al.* (2018)					X						X
van Dooren *et al.* (2019)					X					X	X
van Dooren *et al.* (2020)					X					X	

Table 1.
Set of 58 contributions per author, measurement methodology and food supply stage

(*continued*)

References	Food supply chain stage						Measurement methodologies				
	AG	PR	RE	HO	HOS	DI	DM	LCD	MB	QSI	WAC
van Herpen *et al.* (2019)					X	X				X	
Velasco *et al.* (2019)	X	X	X								
Wang *et al.* (2017)				X			X			X	
Wesana *et al.* (2019)	X	X	X							X	
Willersinn *et al.* (2015)	X	X	X	X	X			X		X	

Note(s): *List of acronyms*: AG = Agricultural Stage; PR = Processing; RE = Retail and distribution; HO = Hospitality industry; HOS = Households; DI = Diaries; DM = Direct measurement; LCD = Literature and companies' data; MB = Mass balance; QSI = Questionnaire, interviews and surveys; WAC = Waste analysis composition

Source(s): Personal elaboration by the authors

Table 1.

and expertise requirements as well as direct access to food waste streams (through personal observations or communication with farms, companies or retail markets). At households, direct measurement involves kitchen scales, measuring glasses or other conventional measurement tools (Khalid *et al.*, 2019). Among its strengths, it allows for progress updates over time and can track food waste (Commission of Environmental Cooperation, 2019).

As stated by Table 1, a majority of the authors ($n = 14$) applied direct measurement, ranging from agricultural (Hartikainent *et al.*, 2018; Jhonson *et al.*, 2018; Schneider *et al.*, 2019) to retail contexts (Eriksson *et al.*, 2012; Brancoli *et al.*, 2017), with a huge number of studies ($n = 8$) dedicated to the hospitality industry (Costello *et al.*, 2015; Boschini *et al.*, 2018) and only one on households (Khalid *et al.*, 2019). Methodologically, six articles investigated food waste with a mixed approach of matching direct measurement with literature and company data (Eriksson *et al.*, 2012), questionnaires (Pflugh Prescott *et al.*, 2019) or both (Hartikainen *et al.*, 2018; Beretta and Hellweg, 2019), to fill data gaps.

Table 3 presents direct measurement specific approach and main findings from selected studies.

4.3 Mass balance

The mass balance approach measures food loss and waste by comparing inputs with outputs and accounting for changes in stock levels. As stated by Beretta *et al.* (2013), Pirani and Arafat (2016) and Caldeira *et al.* (2019), one of the most common approaches to account for food loss and waste is Material Flow Analysis (MFA), which been successfully applied at different levels, from single products (Amicarelli *et al.*, 2020) to industrial sectors (Pirani and Arafat, 2016), but also at a macro-level in analyzing entire national systems (Beretta *et al.*, 2013, in Switzerland) and wider geographical areas (Caldeira *et al.*, 2019, in the European Union). Brunner and Rechberger (2017) defined MFA as a "systematic assessment of the state and change of material flow and stock in space and time." It is based on the mass-balance principle, connecting input material and energy flows to output flows in terms of final products, sources, pathways, by-products and waste (Brunner and Rechberger, 2017; Zaghdaoui *et al.*, 2017).

If input and output data exist, the mass balance approach can return, rather economically, a series of estimations on food loss and waste that would otherwise not be obtainable. For this reason, a majority of the studies conducted through this methodology investigates the whole food supply chain, from agriculture to final consumption. Moreover, considering that MFA offers a highly detailed perspective on the agri-food sector stressing waste hotspots (specific phases, quantity evaluations and quality characterizations) in food production in a highly comparable way, it represents a fundamental and transparent basis for decision makers and a

Table 2.
Main findings from diaries

References	Design/methodology/approach	Period	Sample	Results
Langeley *et al.* (2010)	Food waste diary using consumer self-assessment method, because it is the most accurate real measurement of food waste actually entering the waste stream	Seven-days study period	13 households (33 individuals) in the UK	Average of 0.199 kg of food per person per day. Food waste to landfill: 0.14 kg per person per day
Katajajuuri *et al.* (2014)	Kitchen diary study maps volume and composition of food waste. Each participant was paid 30 euro and was allowed to keep the electronic kitchen scale provided for weighting food waste	September 2010. Two-week study period	380 households (1054 individuals) in Finland	Average annual food waste ranged from 0 to 160 kg per person. On average, 23 kg per person and 63 kg per household
Silvennoinen *et al.* (2014)	Follow-up study concentrating on mapping the volume and composition of avoidable solid food waste and liquid milk waste in households. Phone guidance available, but never requested	September 2010 Two-week study period	380 households in Finland	Global households waste: 882 kg per two weeks. Average household waste per two-weeks: 0–23.4 kg. On average, households discarded 2.3 kg, thus 837 g per person per week (59 g per person per day)
Richter and Bokelmann (2017)	Dairy is made out of four questionnaires to list food storage, food purchase, food waste and attitudes/perceptions towards food and food waste, plus guide with background information	August–November 2014 Seven-day study period	25 households in Germany	Not available data by diaries
Delley and Brunner (2018)	Two different approaches: the main one, consisting on food frequency in a self-reported written form; the alternative one, combining data about disposal routes and results from waste compositional analysis	May–June 2016	506 households in Switzerland	396 g of food per households per week, or 171 g per person per week, corresponding to 8.9 kg per capita per year
Giordano *et al.* (2018)	Diary and questionnaire reliability evaluation with waste sorting analysis performed on 12 sub-sample out of 20 units. Quantities of self-perceived (questionnaire), self-reported (diary) and actual (waste sorting) food waste compared	One-week study period	20 households in Italy	Edible food waste estimated in 489 g per household per week based on questionnaires, and 1,035 g per week based on diaries. In sub-samples, food waste of 334 g per week based on questionnaires, 818 g per week based on diaries and 1,058 g per week based on waste sorting analysis

(*continued*)

Table 2.

References	Design/methodology/approach	Period	Sample	Results
Giordano *et al.* (2019a)	Household members in-charge of shopping and food management were required to record the quantity of food waste produced within the household on a daily basis, including key details on food thrown away	February 2017	385 households in Italy	Quantity of household food waste amounted to 0.530 kg per person per week (27.5 kg per person per year) and 1.224 kg per household per week
Giordano *et al.* (2019b)	Two different phases: diary stage and questionnaire stage. Respondents received 50 euro to join the experiment (shopping vouchers)	May–June 2017	388 households in Italy	Overall per person food waste: 530 g per week. Single households: 717.7 g per week. Families of three members: 375 g per capita per week. Families composed by four members of more: 424.5 g per week
Leverenz *et al.* (2019)	Comparison of two different types of coaching methods to reduce avoidable food waste in households. Panel 1: offline self-reporting system and personal communication through face-to-face dialogues during coaching sessions. Panel 2: web-based online platform to communicate and display information	Panel 1 March–May 2011 Panel 2 March–May 2012	Panel 1: 16 households, in Germany. Panel 2: 37 households, in Germany	Panel 1: before coaching 49.08 g per capita per day, after coaching 19.81 g per capita per day Panel 2: before coaching 34.93 g per capita per day, after coaching 16.16 g per capita per day
van Herpen *et al.* (2019)	Participants recorded the weight for each waste instance (in grams), state, product category and if the waste was thrown in the bin, otherwise participants were asked to simply describe other disposal methods. Respondents received 40 euro to join the experiment	One-week study period	143 members of a consumer panel in Netherlands	1,055 g per week per households, thus 150 g per day per household
Ilakovac *et al.* (2020)	Preliminary research to evaluate best method among weighting, quantity estimate or self-assessment. Then, selection of self-assessment method as most convenient, precise and user-friendly	May–September 2017. Seven-days study period, from Monday to Sunday	118 households in Croatia	Weekly amount of food waste per households: 3.64 ± 2.52 kg. Daily amount of food waste per households: 0.52 ± 0.36 kg. Average weekly amount of food waste per household member: 1.44 ± 1.08 kg. Average daily amount of food waste per household member: 0.21 ± 0.15 kg
Moreno *et al.* (2020)	Kitchen diaries with food description, mass (in ounces), state of food (inedible parts, cooked, whole), loss reason and discarded destination	Late 2016 and early 2017. One-week study period	489 households in Denver, CO and New York City, NY	Approximately 1,337 kg of food per 489 households per week. 2.73 kg of food per household per week, thus 0.39 kg per household per week

Table 3.
Main findings from direct measurement

References	Design/methodology/approach	Specific sector investigated	Sample	Results
Eriksson *et al.* (2012)	Products with barcode scanned and saved in supermarket's database. Products without barcode weighted and manually entered into the database	Retail	6 stores located in the Stockholm-Uppsala region of Sweden (Willys chain)	Total food waste in 2010 per category. Potato: 10 t. Lettuce: 7.31 t. Tomato: 6.75 t. Sweet pepper: 5.37 t. Carrot: 4.50 t. Banana: 4.37 t. Apple: 3.78 t. Orange: 3.74 t. Grape: 3.66 t. Pear: 3.06 t
Kallbekken and Saelen (2013)	All hotels recorded and reported the amount of food waste	Hospitality (hotel restaurants)	53 hotels from Nordic Choice Hotels	Pre-treatment food waste (average): 39.90 kg per hotel. Post-treatment food waste (average): 31.02 kg
Costello *et al.* (2015)	Food waste collected from facilities, transported to other location, separated into different food categories and weighted	Campus dining operations	4 different facilities at the University of Missouri in Columbia (US)	Pre-consumer food waste: 24.6 g per customer (6.7 inedible and 17.9 edible) Post-consumer food waste: 47.1 g (9.4 inedible and 37.7 edible)
Brancoli *et al.* (2017)	See Eriksson *et al.* (2012)	Retail (mid-size urban supermarket)	1 supermarket located in the city of Boras (Sweden) with a sale area of 410 m^2	Waste from October 2014 to September 2015: 22.5 t of food
Eriksson *et al.* (2017)	Data collection by the kitchen staff using electronic kitchen scales, pen and paper for making notes and an Excel spread sheet. Portions served measured by the number of plates used by service	Public catering services	30 kitchen units including 4 elderly care homes, 14 schools and 12 preschools in Sweden	On average, 75 g per portion was wasted, of which 64% of serving waste, 33% of plate waste and 3% of other waste
Strotmann *et al.* (2017)	Three parts: visit and measurement parts taking place on-site at the food service facilities, and analysis phase taking place off-site. Measurement of patients', customers' and residents' plate waste for all meals with electronic scales	Hospitality	3 institutions: one hospital, one cafeteria and one retirement home, in Germany	Hospital waste rate: 25.6% +/− 4.6% Cafeteria waste rate: 19.8% +/− 8.3% Retirement home waste rate: 21.4% +/− 6.7%
Wang *et al.* (2017)	See Table 5	See Table 5	See Table 5	See Table 5
Boschini *et al.* (2018)	Direct method with food weighted with an electronic scale. Data aggregated and measured separately across plate types	Hospitality (school canteens)	5 primary schools within the Bologna province (Italy)	Amount of plate waste per person: 114.4 g (edible fraction: 107 g and inedible fraction: 7.4 g per capita)

(*continued*)

Table 3.

References	Design/methodology/approach	Specific sector investigated	Sample	Results
Hartikainen *et al.* (2018)	Different typologies of measurement: questionnaires, direct in-field measurement, interviews and literature data in filling gaps	Primary production (agriculture, aquaculture and fisheries)	6 case products in Finland, Sweden, Norway and Denmark	Total amount of food waste estimated in 800,000 t per year, plus additional 100,000 t per year from the rearing phase of animals
Johnson *et al.* (2018)	Food waste samples collected, sorted, weighted and recorded, then information is used to calculate average harvest remained on the field (t/ha)	Primary production (agriculture, aquaculture and fisheries)	13 fields of 121 ha in North Carolina, US	On average, on-farm food loss is: 0.10 kg per plant still marketable; 0.25 kg per plant edible but unmarketable; 0.18 kg per plant inedible
Beretta and Hellweg (2019)	Physical assessment partly combined with staff members interviews and with literature data in filling gaps	Food service sector (health, education, hotels and restaurants)	13 case studies in Switzerland, Germany, Austria, Finland and the UK	Restaurant (buffet): 105 g per meal Restaurant (beer hall): 104 g per meal Primary school: 147 g per meal Hospital: 302 g per meal Hotel: 64 g per meal Business canteen: 189 g per meal
Giboreau *et al.* (2019)	Photos automatically taken by a camera on a tripod from 1 m distance and 45-degree angle	Hospitality (school cafeteria)	1 school cafeteria self-service, 215 children (776 trays) in France	Vegetables were significantly the most wasted food, especially cooked, either served warm as side dish (66% wasted) or cold as a starter (42% wasted)
Khalid *et al.* (2019)	Plastic bags given to households to keep their one-day (24 h) food waste. Each food waste fraction was weighted separately, and its weight was recorded	Households	51 households in Kahror Pakka Tehsil of District Lodhran, Punjab, Pakistan	Cooked food wasted: 35.01 g per household per day. Vegetables wasted: 11.62 g per household per day. Fruits wasted: 9.78 g per household per day. Cereals wasted: 2.45 g per household per day. Dairy wasted: 1.98 g per household per day
Pflugh Prescott *et al.* (2019)	Mixed methodologies including interviews, kitchen observations and food waste direct measurement. All wasted food was collected and measured. The final total amount was calculated by mass per serving from district recipes and product specifications	Hospitality (school canteens)	13 school kitchens and 1 district centralized kitchen in Colorado, US	On average, 43.8 g of food waste per student, of which 74.2% still edible. In addition, 15.2 mL of liquid food waste per student
Schneider *et al.* (2019)	On-site measuring per harvest losses for potatoes (2013), repeated in 2014	Primary production (potato production)	6 case studies in Austria and Germany	Average non-harvested potatoes: 0.7 t/ha Average over-sized, damaged and sorted out potatoes: 0.9 t/ha

well-grounded inventory of other methodologies (e.g. life cycle assessment), environmental indicators (carbon and water footprint) and environmental-management tools (e.g. ISO 14001). However, one of the main limitations of the mass balance approach is the lack of data since reliable and costly data are necessary to build a robust and complete MFA. Furthermore, several data inaccuracies and difficulties have been detected when estimating uncertainties, but such limits can be by using specific software such as STAN 2.6.801 (Beretta *et al.*, 2013; Cencic and Rechberher, 2008; Cencic, 2016a, b). Table 4 presents the main findings from selected studies ($n = 4$).

4.4 Questionnaires, surveys and interviews

A majority of the authors applied questionnaires and/or interviews ($n = 20$). According to Møller *et al.* (2014), a questionnaire is a formal, structured way to collect quantitative or qualitative data from participants and could be applied to obtain food waste amounts, figures and other additional information from producers (growers), processors, retailers and consumers (e.g. waste behaviors, waste management, awareness of the problem). Generally, questionnaire, surveys and interviews are treated as synonyms and could be divided into two categories: those used to collate existing data (to assess reliability) and those used to estimate

Table 4.
Main findings from mass balance approach

References	Layer/Place	Main features	Results
Beretta *et al.* (2013)	Single nation/ Switzerland	22 food categories: fruits (apple, fresh fruits, berries, canned fruits), vegetables (potatoes, fresh, storable and processed vegetables), cereals (bread and durum wheat, rice, maize) sugar, oils and fats, dairy (milk, cheese, butter), eggs, meat (pork, poultry, beef), fish	Harvest Losses: 2,200 TJ Conversion losses from feed to animal products: 125,000 TJ Dairy, egg, meat production losses: 1,370 TJ Postharvest losses: 420 TJ Processing losses: 1,490 TJ Retail losses: 460 TJ Households waste: 6,570 TJ Food service industry: 925 TJ
Pirani and Arafat (2016)	Hospitality sector/United Arab Emirates	First, daily food waste data from the canteen at Masdar Institute of Science and Technology in Abu Dhabi, while the second method involved an MFA for the different events that authors monitored at various hotel restaurants	A la carte: preparation waste (10%), food waste from customers' plates (12%) Breakfast buffet: preparation waste (5%), food waste from customers' plates (4%), food waste from serving dishes (7%) Lunch buffet: preparation waste (15%), food waste from customers' plates (14%), food waste from serving dishes (44%)
Caldeira *et al.* (2019)	Continent/ European Union	Investigation on meat, fish, dairy, eggs, cereals, fruits, vegetables, potatoes, sugar, oil crops	Primary production losses: 32.2 Mt Processing and manufacturing losses: 30.6 Mt Retail and distribution: 6.7 Mt Households: 49.6 Mt Food services: 10.3 Mt. Total: 129.2 Mt
Amicarelli *et al.* (2020)	Potato industry/ Italy	Ready-to-eat (chips) and dried potatoes	Harvest losses: 22,000 t of fresh tubers (3,500–4,800 t of starch and 52,000–72,600 GJ) per year Processing losses: 23,000 t of skins and scraps per year

new food waste amounts (Commission of Environmental Cooperation, 2019). Questionnaires can be conducted by e-mail, by telephone, electronically (online) or in person (face-to-face). In terms of strengths, these methodologies are cost-effective, can be standardized, are some of the most popular methods and can reach high numbers of people. However, they rely on third parties and sometimes create confusion among participants, and respondents tend to underestimate the amount of waste they create. Furthermore, low response rates have been recorded. Table 5 illustrates the main features from questionnaires.

4.5 Waste composition analysis

Waste composition analysis is a methodology of physically separating, weighing and categorizing food waste streams from other materials that are not considered food waste, such as packaging or other solid waste items. Of the selected articles ($n = 7$), the majority ($n = 6$) analyze food waste at households, while only one analyzes the hospitality sector (Rajan *et al.*, 2017), and three articles applied mixed methodologies, comparing the results of diaries (Delley and Brunner, 2018) or questionnaires (van Dooren *et al.*, 2019) with those of national waste composition reports or evaluating questionnaires' reliability (Giordano *et al.*, 2018). Table 6 illustrates the main features of the waste composition analyses.

Waste composition analysis provides accurate data and offers information on food waste (e.g. for packaged or unpackaged food as well as vegetables or fruits), which can help with further analysis of financial costs and nutritional content. However, this methodology is costly, requires large sample sizes and does not provide information on the reasons for food waste (Commission of Environmental Cooperation, 2019).

5. Conclusions

Through a systematic, configurative literature review, this paper highlights the importance of choosing measurement methodologies according to the geographical area of interest, the food supply chain stage and the availability of data, which represent the three main pillars of food waste assessment. To this extent, the authors have identified some key points for implementing further research of food waste accounting and for directing programs and policies to manage and reduce food waste and ensure food security and safety.

(1) *Data availability.* Data are crucial for achieving a good and clear understanding of global food loss and waste quantities and quality. They are the essential prerequisite for assessing the effectiveness of interventions, both to evaluate the social, economic and environmental impacts of food loss and waste and to achieve sustainable international goals.

(2) *Measurement programming.* Food waste measurement programming should first establish a commonly accepted definition of food waste and the area and food supply chain stage of interest because a suitable measurement methodology is more likely to give sufficient, useful and punctual results that will be helpful for policy makers. For instance, analyses of food waste in developed countries should address consumer habits and behaviors because the highest incidence of food waste occurs exactly during final consumption stage, while investigations within developing countries should focus on agricultural, storage and processing techniques. The fact that they are not efficient, combined with the lack of structural infrastructures, is the main cause of food loss and waste in these countries.

(3) *Comparability and replicability.* The need for comparability and replicability imposes the suitable identification of functional units and boundaries for the analysis – which are not always well defined or declared in space and time – since only a few studies

Table 5.
Main findings from questionnaires, interviews and surveys

References	Design/methodology/approach	Area of interest	Sample features	Results
Katajajuuri *et al.* (2014)	See Table 2	See Table 2	See Table 2	See Table 2
Willersinn *et al.* (2015)	From harvesting to distribution, approximately one week before the interview took place, a standardized 8-page questionnaire was sent by email to people in-charge of preparing meals, to complete it according to quality standards, to the extent of potato losses, to their collaboration with supply chain partners, and with ecological and economic data	Potato supply chain in Switzerland	3 wholesalers (fresh potatoes), 2 wholesalers (processing potatoes), 4 processing industry, 5 retailers, 704 households	From the total initial fresh potato production, 15–24% gets lost during agricultural production, a further 12–24% at wholesalers, 1–3% at retailers, and 15% at private households. In comparison, 5–11% of the initial production gets lost at wholesalers, a further 14–15% during processing, 0% at retailers, and 2% at private households
Pirani and Arafat (2016)	Face-to-face interviews between the authors and representatives of hotels/organizations (head of engineering, environmental manager, food safety and hygiene manager)	Hospitality sector, taking United Arab Emirates and Abu Dhabi as examples	45 hotels/restaurants	Not available data by interviews
Amato and Musella (2017)	Interviews listed from October to December 2016. Interviews schedule was anticipated by telephone calls and letters describing the research content	Restaurant business in historic center of Naples (Italy)	89 completed questionnaires	Total waste per year: 7,446 quintals (bar waste: 3,232 quintals; restaurant waste: 4,214 quintals)
Chakona and Shackleton (2017)	Face-to-face interview of an average of 1 h and 45 min	Household data collected between October and November 2014 in Richards Bay, in Dundee and in Karrismith (South Africa)	554 households	Overall mean quantity of food waste for 48 h: 121 g of prepared food, 268.6 g of unprepared food and 77 mL of drinks per household

(*continued*)

Table 5.

References	Design/methodology/approach	Area of interest	Sample features	Results
Tostivint *et al.* (2017)	Literature review as well as preparatory phone interviews listed to collect data. Important data were collected by: Nestlé, farms, VMCs and CCs, distributors and retailers. In addition, interviews with experts of the Pakistani dairy sector, and a focus group with consumers were organized. Face-to-face interviews conducted with three experts which were sent questionnaires	Primary production, processing and distribution in dairy supply chain in Pakistan	18 farms, 8 distributors and retailers, 3 experts	Milk waste in strict sense represents around 7,000 t per year
Wang *et al.* (2017)	Two questionnaires were used to investigate the amount and composition of food waste and consumer food waste behaviors. The first part is a weight table which includes the quantity of food offered and wasted in the plate	Restaurants in four cities (Beijing, Shangai, Chendu, Lhasa)	195 restaurants with 3,557 tables. For each restaurant, 20 tables of consumers were randomly selected	The average amount of food waste per capita per meal in the four cities is calculated as 93 g in 2015
Giordano *et al.* (2018)	See Table 2	See Table 2	See Table 2	See Table 2
Hartikainen *et al.* (2018)	Interviews supported final results of previously collected 21 questionnaires	Primary production in Nordic countries	2,500 responses (including some producers representing several farmers)	Food waste estimated in 800,000 t per year plus 100,000 t from rearing phase of animals. Changing boundaries, food waste amount is 330,000 t per year
Szabò-Bòdi *et al.* (2018)	Consumer survey required the following equipment: general EC standard kitchen scale (accuracy in grams), measuring jug (600 mL) and datasheet. These items were provided by the research team to the households to ensure consistency in the measurement process	Household in Hungary, one week from August to November of 2016	100 households (295 people)	Estimated quantity of total food waste (including liquid waste) per capita is 68.04 kg per year. Avoidable food waste is equal to 33.14 kg per capita per year

(*continued*)

Table 5.

References	Design/methodology/approach	Area of interest	Sample features	Results
Baker *et al.* (2019)	In-depth interviews to understand how production, yields and loss vary throughout the growing season. At least two interviews per crop have been conducted and continued interviewing growers until the development of comprehensive understanding of the pattern and amount of these losses	Primary production in northern and central California, summer and fall 2018	20 crops in 123 fields	On average: 11,185 kg per hectare of edible produce left in field after harvest
Djekic *et al.* (2019)	All interviews were performed face-to-face with a brief guide over the research aim	Household survey performed during the first half of 2018 in Sarajevo and Banja Luka, Bosnia and Herzegovina	801 citizens	Households disposed around 2.78 kg of food per week, or 0.95 kg per capita, which means 145 kg annually of food waste
Elimelech *et al.* (2019)	Hybrid approach: physical waste survey and food expenditure survey, as well as self-assessment in the form of a questionnaire-based survey (self-assessment of food waste amount, self-assessment of food waste proportion and self-assessment of monetary losses)	Households investigated on three neighborhoods of the Haifa Municipality, Israel	187 households	Avoidable food waste amounted to 3.069 kg per household per week (0.927 kg per capita per week). Monetary losses were on average 42.07 euros per household per month
Giordano *et al.* (2019b)	Diary stage (see Table 2) and questionnaire stage. Questionnaire sent to respondents two weeks after the end of the diary survey, for an amount of 23 questions including estimate of food waste	Households. National survey conducted in May–June 2017 in Italy	388 families	Overall per person food waste average is 530 g
Pflugh Prescott *et al.* (2019)	This study follows mixed methods, using key respondent interviews and 80 h of structured kitchen observations (see also Table 3)	School and district kitchens using stratified random sampling in Colorado school districts in 2016–2017	14 schools and district kitchens	Pre-consume average rates: 43.8 g per student, of which 32.5 g of edible waste

(*continued*)

Table 5.

References	Design/methodology/approach	Area of interest	Sample features	Results
van Herpen *et al.* (2019)	Four different survey measurements of general food waste were included in the initial online survey: (1) general waste assessment (2) frequency of wasting food in general (3) waste assessment per category (4) food waste in past week	Households from a consumer panel of Wageningen Food and Biobased Research (Netherlands)	143 members	The average amount of food waste in grams per week per household ranged between 614 and 1,220 g
Wesana *et al.* (2019)	Observations made along the dairy value chain and interviews conducted with key personnel operating within the chain	Three levels of the value chain: farm, processing and distribution, in August 2017 in Western Uganda	One vertically integrated dairy chain	Losses at the end of dairy chain: 1,409 kg (milk), 337.4 kg (plain yogurt) and 159.2 kg (mango yogurt)
Eriksson *et al.* (2020)	Online survey. One contact person in each of Sweden's 21 regions was sent the questionnaire by e-mail	Hospital food waste quantification routines in Sweden	20 hospitals in three regions out of 102 hospitals (and hospital units)	Average level of food waste in the hospitals was 111 g per guest per meal, with lowest value of 27 g and highest of 184 g per guest per meal. Globally, waste level varied between 1.9 and 239 kg per day per hospital
van Dooren *et al.* (2020)	The questionnaires were supposed to be comparable one with another. Additional online Facebook questionnaire and professional clients to evaluate measuring cup reliability	Households in Netherlands	Client panel of supermarket: 666 individuals. Online Facebook questionnaire: 445 responses. Professional clients: 150 individuals	The *Eetmaatje* provides a theoretical reduction of food waste of 6% for pasta and 21% for rice, or 12.5% combined
Kasza *et al.* (2020)	Questionnaire in which households were supported by kitchen scales, measuring glasses and a manual	Households in Hungary	165 households	Globally, 532.76 kg of food waste generated, of which 475 kg solid and 57.75 kg liquid. Total per capita food waste was 65.49 kg per year

References	Design/methodology/approach	Sample features	Results
Hanssen *et al.* (2016)	Waste was collected by the municipalities on ordinary collection dates and represented one week of waste from each household. Waste from each household was collected in 160 L waste bags. For food waste in original packaging, the packaging is included in food weight	12 households recruited in Fredrikstad and Hallingdal (Norway). All inhabitants in the sampling areas received a letter informing them about the anonymous waste sampling	Food waste per household per week: 3.76 kg on average, of which 2.17 kg edible and 0.60 kg of edible food in original packaging
Rajan *et al.* (2017)	Food wastes collected in campus composting green bins	2 primary foodservice providers at Prince George Campus in Columbia, US	1.1 t of food waste per week
Delley and Brunner (2018)	Data from national waste compositional analysis conducted by the Swiss Federal Office for the Environment. The authors divided biogenic waste into other foods, preparation waste, garden waste and meat/fish	See Table 2	National waste composition analysis resulted in a total of 89.4 kg of mostly avoidable household food waste per capita per year
Elimelech *et al.* (2018)	Mix of physical waste survey with measurement of municipal solid waste composition. The method is based on the principle of measuring waste of individual households on a daily basis. It includes the following four elements: (1) capturing food waste at the point at which it enters the waste stream (2) collecting waste samples at the doorstep (3) using the individual household as a sampling unit (4) collecting and sorting waste daily	192 households (634 individuals). 1,257 waste bags were analyzed during the study in Israel	Globally, 2,543.56 kg of food waste produced, of which 601.73 kg avoidable. Daily generation rate of 0.573 kg per capita
Giordano *et al.* (2018)	See Table 2	See Table 2	See Table 2
van der Werf *et al.* (2018)	Household waste composition study data (2012–2015), including a single "food waste" category, were gathered from nine Ontario municipalities, aggregated and analyzed to develop estimates of food waste in the garbage stream	28 single-family households in Ontario, Canada	On average, households disposed 2.40 kg per week of food waste in the garbage

Table 6.
Main findings from the waste composition analyses

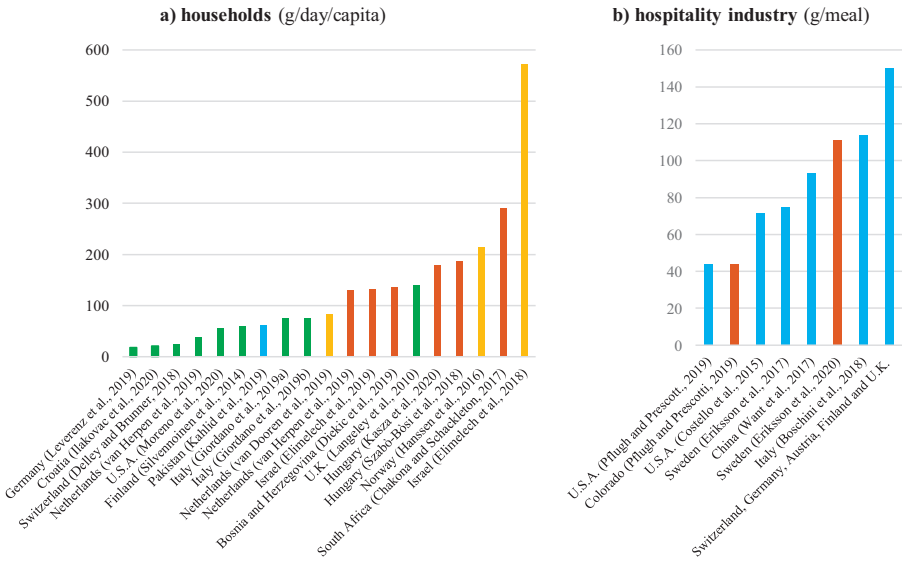
(*continued*)

References	Design/methodology/approach	Sample features	Results
van Dooren *et al.* (2019)	In order to determinate the food waste household composition, a classification analyses were performed in 13 municipalities, referring at residual waste (13 municipalities) and vegetable, fruits and garden waste (VFG). The residual and VFG waste of each household was manually sorted on a table at a central location	240 samples of 130 households (130 of residual waste and 110 for VFG in Netherlands	Declining trend in food waste per person per year from 37.4 kg in 2010 to 34.6 kg in 2013 and 30.4 kg in 2016

Table 6.

included in the present review could be compared. A majority of them, as stated by Figure 5, are about the final consumption stage, in both households ($n = 19$) and the hospitality industry ($n = 8$). The studies conducted on the upstream stages are not comparable due to their different functional units and/or boundaries: e.g. agricultural-stage results refer to t/year or t/ha, while those from the retail stage indicate t/month. For this field, the authors suggest expressing food waste in t/m^2.

The literature about food loss and waste is not silent (as reported in Figure 2), but it is necessary to coordinate and to converge studies and research toward a well-organized



Methodological approaches: green = diaries; orange = questionnaires; yellow = waste analysis composition; blue = direct measurement

Source(s): Personal elaboration by the authors

Figure 5.
Comparison of studies involving households (a) and the hospitality industry (b)

objective: measuring food waste. The problem is *how*, *where* and *when* to measure this phenomenon. Although each methodology seems to have its own strengths and weaknesses, the authors are convinced that a mix of mass balance approach and food diaries could be helpful towards food waste minimization.

To analyze the upstream stages (from agricultural production to retail), where approximately 50% of global food waste occurs, the authors suggest the application of the mass balance approach. Such methodology, even with its limitations (data scarcity and high costs of data collection), can return a sequence of quali-quantitative information on input and output flows, becoming a useful instrument to evaluate agri-food systems efficiency and circularity, supporting at the same time waste and energy managers in the enhancement of food waste minimization and consequently sustainable development programs. Moreover, both at micro (single product, single industrial plant) and macro (countries) level, mass balance results represent a reliable inventory to evaluate costs (e.g. through Material Flow Cost Accounting, Life Cycle Costing) and environmental impacts (e.g. Life Cycle Assessment). Lastly, in terms of sustainable communication and transparency, flow diagrams (e.g. Sankey diagrams) are extremely clear and communicative, improving consumers' awareness on food waste.

As regards downstream stages (canteens, restaurants, hotels and households), food diaries could represent an interesting – but complex – option, considering that food waste is recorded each time it occurs. As already discussed, indoor/outdoor food waste data collection is crucial, being fragmented and differing from one person to another. However, relying on general participants' enthusiasm, availability of mobile-apps and other engaging technological tools, problems of recruitment and underestimation (typical of questionnaires, surveys and interviews) could be overcome. Key point to improve food diaries' efficiency is consumers coaching. Furthermore, food diaries include significant information on waste generation steps, main reasons for discarding and disposal procedures, becoming a useful tool to understand, and correct, actual unsustainable consumers behavior.

Up today, less than 30% of world's total agricultural land is used to produce roughly 1.3 billion tons annually of food loss and waste, equal to one-third of the global food produced for human consumption (Gustavsson *et al.*, 2011; FAO, 2013; International Food Policy Research Institute, 2019). This enormous quantity is still potentially fit for human consumption, which would decrease food insecurity, ensure daily intakes and be correlated with healthy status. It is estimated that saving one-fourth of the food wasted would make it possible to feed all currently undernourished people (Basher *et al.*, 2013; Irani *et al.*, 2018). Based on European food waste composition (Caldeira *et al.*, 2019), the authors have estimated that, in terms of energy intake, each year more than 5,200 billion MJ are globally wasted along the whole food supply chain. This amount would actually feed worldwide hungry people (800 million people) for more than 2 years.

Hungry, undernourished and over-weight people represent three different aspects of unhealthy diet and, together with food waste, are some of the key elements accounted into the paradox of actual human nutrition system. As illustrated by the present review, several world regions are unjustifiably not involved and/or probably not interested in food waste measurement. Food waste appears to be a scarcely investigated phenomenon under quantitative and qualitative perspective, due to the lack of homogeneous, standardized and comparable measurement systems. Further efforts are needed to cover never-analyzed countries, improve already-analyzed ones and return a global extent of food waste phenomenon, including developed and developing economies in each feature of their food production/consumption.

To manage food security, ensure health and reduce hunger, undernourishment and overweight, achieving the international sustainable goals, it is essential to perform food waste reliable analysis and *rebalance* the actual inadequate food-system, implementing new

models of food production, consumption and disposal towards a fair, healthy and environmental-friendly food-system.

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