

A systematic review of food losses and food waste generation in developed countries

1 Paul van der Werf BSc (Agr), MSc
PhD Candidate, Department of Geography, Western University,
London, ON, Canada (corresponding author: pvande2@uwo.ca)

2 Jason A. Gilliland BA (Hon), MA, MArch, PhD
Professor, Department of Geography, Western University, London, ON,
Canada



The objective of this systematic literature review was to compile and assess food losses and waste estimates, from developed countries, across the food supply chain. The methodology involved systematically identifying studies and extracting, compiling and analysing their estimates of food losses and waste. Of the 55 estimates extracted, from these studies, the most (43.6%) were from the consumption (average 114.3 (kg/capita)/year) part of the food supply chain. On average, total food losses and waste were 198.9 (kg/capita)/year. While this review revealed a high degree of variability of estimates and inconsistent trends for the independent variables: scope of food waste, geography and study methodologies; food waste generation, at the consumption part of the food supply chain, was significantly higher for North American compared with European estimates ($p=0.003$); and significantly higher ($p=0.030$) for indirect than direct estimates. Similarly, total food waste generation indirect estimates were significantly higher ($p=0.035$) than directly measured estimates. To improve the accuracy and precision of food losses and waste estimates, additional research is required to develop and implement a bespoke, weight-based and statistically sound methodology for its direct measurement.

1. Introduction

World food production has increased substantially in the past century, as has calorie intake per capita (Nellemann *et al.*, 2009). Nevertheless, food insecurity persists: according to the Food and Agriculture Organization (FAO), 795 million people are undernourished globally, including 15 million in developed regions (FAO *et al.*, 2015).

The quantification of food losses and waste (FLW) is being used to draw attention to the poor use of food resources. According to Gustavsson *et al.* (2011), developed countries generate more FLW than developing countries. Its reduction presents opportunities to reduce its economic (e.g. wasting money), environmental (e.g. greenhouse gas (GHG) generation) and social (e.g. food security) impacts. To develop effective FLW reduction interventions and measure their impact, it is essential to have a more precise understanding of its generation. Since a variety of methods have been used to collect FLW data, precise estimates have been elusive. The objective of this systematic literature review is to compile and critically

assess current annual per capita weight-based estimates of FLW along the various parts of the food supply chain (FSC) in developed countries.

Figure 1 depicts the various parts of the FSC that consist of ‘agricultural production, postharvest handling and storage’, processing and packaging, ‘distribution (i.e. retail sale)’ and ‘consumption’. The authors’ conceptualisation incorporates system boundaries adapted from Gustavsson *et al.* (2011), Nahman and de Lange (2013) and Parfitt *et al.* (2010). It highlights the progression of food from farmers to consumers. Each stage of the FSC is a FLW generation and intervention point.

Schneider (2013) summarises a number of definitions that have been applied to FLW. In this paper, the front part of the FSC (Figure 1) encompasses ‘agricultural production, postharvest handling/storage and processing’, with food that becomes unavailable for human consumption referred to as food losses (Gustavsson *et al.*, 2011; Kummu *et al.*, 2012; Parfitt *et al.*,

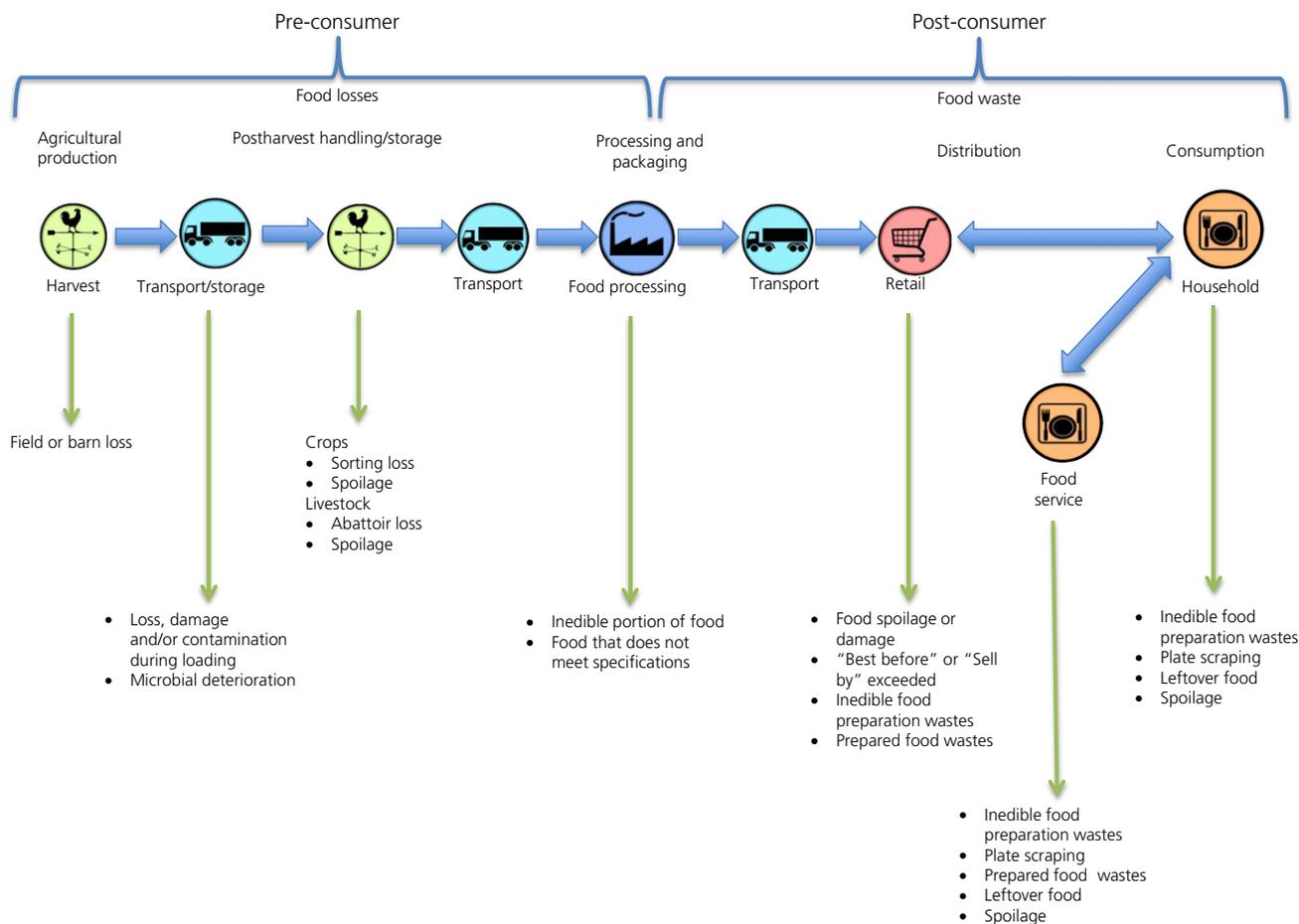


Figure 1. Overview of FSC and food losses and food waste

2010). The back part of the FSC encompasses 'distribution' and 'consumption', with food that becomes unavailable for human consumption referred to as food waste (Parfitt *et al.*, 2010). FLW are either deemed edible or inedible, which are referred by some as avoidable or unavoidable food waste, respectively (Beretta *et al.*, 2013; WRAP, 2009). Edible FLW is food that was at one point edible. Inedible FLW is food that was never edible (e.g. vegetable peels, egg shells, bones).

1.1 Annual food production, consumption and FLW generation

The total production of edible food has been estimated at about 900 (kg/capita)/year in North America and Europe (Gustavsson *et al.*, 2011). Meanwhile, estimates of total food available for consumption vary considerably: total food consumption in the developed world has been estimated at 1006 (kg/capita)/year (Alexandratos and Bruinsma, 2012). Per country food consumption estimates include 779 (kg/capita)/year in Canada (Abdulla *et al.*, 2013), 500 (kg/capita)/year in the USA (Kantor

et al., 1997), 500–600 (kg/capita)/year of food purchased for consumption in Finland (Tike, 2010; Viinisalo *et al.*, 2008) and 687 (kg/capita)/year food consumption, at the retail level in Switzerland (Beretta *et al.*, 2013).

Parfitt *et al.* (2010) reported that there is no consensus on the amount of global food production that is lost, with ranges of 10–40% and up to 50%. Gustavsson *et al.* (2011) estimated that a third of the food produced for human consumption, or about 1.3 billion tons/year is lost or wasted annually, but because many assumptions had to be made to develop these estimates, they note that the results must be interpreted with great caution. It was estimated that developed regions (Europe and North America) generate 95–115 (kg/capita)/year FLW, which is considerably higher than for developing regions (Sub-Saharan Africa and South/Southeast Asia), which generate 6–11 (kg/capita)/year. Abdulla *et al.* (2013), using Statistics Canada and World Bank data (1961–2009), estimated that the amount of FLW in Canada averaged 40% of food available

for consumption and that in 2009 ~7.3 Mt was wasted in Canada. Agriculture and Agrifood Canada (AAFC, 2015) reported there were ~6 Mt/year of FLW from retail and household consumption.

1.2 Data gaps

There is some agreement among researchers about the state of FLW estimates. According to Parfitt *et al.* (2010), there is no consensus on the amount of FLW due to data gaps and uncertainties. Furthermore, many existing estimates link back to the same limited primary datasets, with much of the published data originating from fieldwork undertaken in the 1970s and 1980s. Langley *et al.* (2009) concluded that calculating and estimating the amount of food waste is a difficult issue due to a lack of real and meaningful data. Indeed, a number of researchers have identified that there are major data gaps in the knowledge of global FLW, that necessitates using secondary (i.e. indirect) rather than primary datasets, and that further research is urgently required to improve FLW estimates (Abdulla *et al.*, 2013; Gustavsson *et al.*, 2011). It is clear that there are some challenges with the available FLW estimates, including how these estimates are gathered and their precision.

Koester (2013) questions how FLW quantities have been calculated and suggests that current estimates are inflated. In questioning the results of Buzby and Hyman (2012), he suggests that rather than summing food losses, calorific values should be presented, although even this approach would result in an over-estimation because in some cases 'food loss could have been economically rational' (Koester (2013): p. 64). Elaborating on these assertions, Koester (2014) posits that the current definition of FLW is inadequate and not suitable for developing policies that contribute to food security, or improve efficiency of resource use and contribute to a sustainable environment. The foremost need is to develop appropriate measures, perhaps using multiple methods, for aggregating FLW across the FSC. Koester's (2013) arguments are echoed by Buzby *et al.* (2014), who note that FLW is becoming an increasingly important topic both domestically and internationally. Better estimates of the amount and value of FLW could help serve as quantitative baselines to develop interventions to reduce FLW generation.

2. Methods

A systematic literature review was performed by adapting methods described in Petticrew and Roberts (2006) and PRISMA guidelines (Liberati *et al.*, 2009). This method, which is widely used in medical and social science fields, has been applied to this review to facilitate a systematic retrieval of relevant research papers. The purpose is to impart additional rigour to the literature review process. This was accomplished by collaboratively developing all search terms, identifying

databases to be used and identifying inclusion/exclusion criteria in advance of starting the review.

2.1 Search strategy

Studies that examined the amount of FLW generated along the FSC were identified through searching the following databases: Scopus, Geobase and Web of Science.

The search included articles published between 1 January 1985 and 15 October 2015. The following search terms were used: 'Food' AND 'Waste' AND Quant*; 'Food Waste' AND Quant*; 'Food Waste' AND 'Characterization'; 'Food Waste' AND 'Cost'; 'Food Loss'; 'Food Losses'; 'Food Waste' AND 'Composition'; 'Food Waste' AND Measure*; 'Food Waste' AND Agri* AND Quant*; 'Food Waste' AND Household* AND Quant*; 'Food Waste' AND Food Process* AND Quant*; 'Food Waste' AND 'Supply Chain' AND Quant*; 'Waste' AND 'Characterization' AND 'Food'; 'Waste Characterization' AND Method*; 'Waste Characterization' AND 'Food'; 'Waste Audit' AND Method*; and 'Waste Audit' AND 'Food'.

The inclusion/exclusion criteria for studies included: (a) detailing research between 1985 and 2015, (b) English language, (c) quantitative and qualitative studies, (d) results of food waste quantification by weight and (e) research conducted in developed countries.

Relevant studies were identified first through title screening and then abstract reviews of titles that passed first screening. Studies remaining after abstract screening were subject to full-text screening and a final decision on relevance for inclusion in the review. Paper relevance was determined through the application of the inclusion/exclusion criteria. Studies from which weight-based FLW quantities could be extracted and normalised on a per capita basis were selected. This was confirmed by both authors.

Data points were extracted from studies and grouped by their respective part(s) of the FSC. Data points were normalised, where necessary, to (kg/capita)/year by dividing the annual weight of food waste generated by the appropriate population. The number of data points per part of the FSC were counted and averaged. The following independent variables were identified: (a) scope of FLW (inedible/edible or edible), (b) geography (Europe or North America) and (c) study methodologies (direct or indirect measurement). Statistical analysis of the data was undertaken by establishing null hypotheses that each independent variable had no impact on the amount of FLW generated for the dependent variables: 'distribution', 'consumption' and 'total' FLW, which were chosen because they had the most FLW data points. This was assessed using an independent sample's *t*-test.

3. Results

Figure 2 depicts the results of the systematic review. After the database search and initial title screening, the authors screened the remaining abstracts of all articles in the reference list, using the inclusion/exclusion criteria. This resulted in a final reference list of 135 papers for full-text review.

The multi-staged search strategy with full-text review yielded 30 papers that met the inclusion criteria for final consideration in this review. The 30 papers included 17 papers that were found directly through the full-text review process and another 13 papers that were identified from a title review of the reference lists of these papers, as well as a scoping review of the grey literature.

3.1 Results of individual studies and study characteristics

Table 1 presents summaries of each of the selected studies. Essentially all the studies were North American (USA and Canada) and European (EU and Scandinavian countries). Almost all studies were undertaken and published after 2005

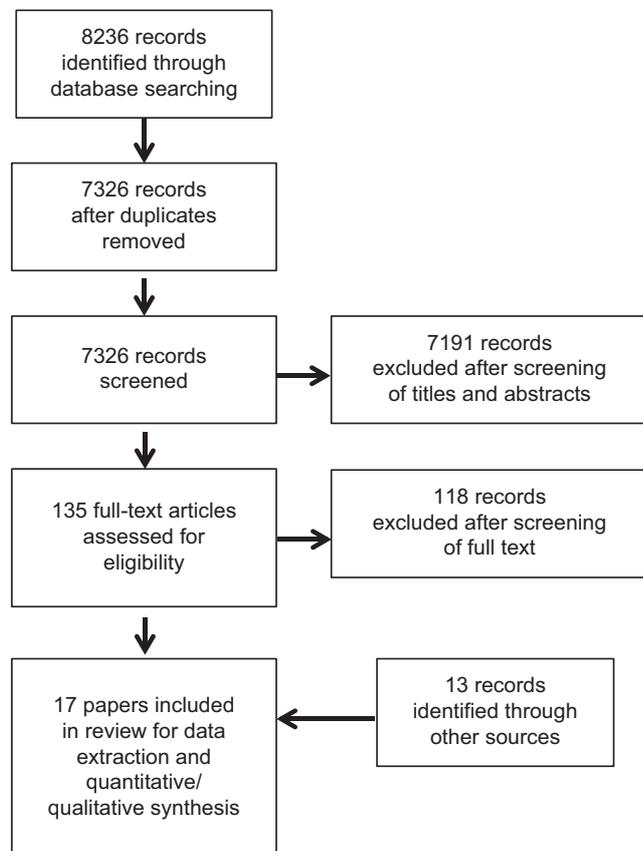


Figure 2. Flow diagram of the systematic review

and include both edible and inedible FLW in their estimates, rather than segmenting out just the edible fraction of FLW. The studies included: regional estimates (e.g. Europe, North America and Oceania – Gustavsson *et al.*, 2011); countrywide estimates (e.g. Canada – Abdulla *et al.*, 2013; USA – Buzby and Hyman, 2012; Buzby *et al.*, 2014); state-wide estimates (e.g. Hawaii – Okazaki *et al.*, 2008), county estimates (Griffin *et al.*, 2009); and neighbourhood estimates (e.g. Malmö, Sweden – Bernstad *et al.*, 2012, 2013). Few studies provided estimates of FLW across each part of the FSC. Quantitative research included mostly uncontrolled studies that combined and extrapolated existing datasets to develop estimates, or the studies of weight-based waste composition measurements. Research studies also included surveys and diaries.

3.2 Review of results by position on FSC

Figure 3 depicts all of the FLW data points by position on the FSC. It is clear that most of the research in these studies was focused on the ‘consumption’ part of the FSC, followed by studies that provided a ‘total’ estimate or ‘distribution’ estimate.

Table 2 presents an overview of the FLW weight data points across the FSC, along with the results of a descriptive statistical analysis. There is a high degree of variability in the estimates across all parts of the FSC.

3.2.1 Agricultural production and postharvest handling and storage

There were three studies that developed estimates for these two parts of the FSC. Brautigam *et al.* (2014) adopted multipliers developed by Gustavsson *et al.* (2011) to estimate FLW and used them to develop a EU-wide estimate of 125.8 (kg/capita)/year for these two parts of the FSC, which represented 44% of their overall estimate of EU FLW.

3.2.2 Processing and packaging

The lower FLW estimates (1.2–3.0 (kg/capita)/year) (both generated using case studies) were from a single upstate New York State county (Griffin *et al.*, 2009) and from a single country (Italy) (Garrone *et al.*, 2014). The highest estimate (70.0 (kg/capita)/year) (based on Eurostat data and data from national sources) was from the EU (EC, 2010) and was similar to a UK-wide estimate (61.7 (kg/capita)/year), which used food production data to develop an estimate of FLW (WRAP, 2013b).

3.2.3 Distribution

The lower estimates of FLW were from the UK (WRAP, 2013b) (7.1 (kg/capita)/year). Estimates for the USA (Kantor *et al.*, 1997) were calculated using US Department of Agriculture Economic Research Service (USDA ERS, 2014)

Table 1. Overview of systematic review results

Author	Year	Country/region	State of food	Method	Study methodology	Food supply chain: (kg/capita)/year					Total
						Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption	
Abdulla <i>et al.</i> (2013)	2009	Canada	Edible and inedible	Used secondary Statistics Canada data, which in turn used USDA 'waste factors', and World Bank data to develop estimates	Indirect					308.2	
AAFC (2015)	2010	Canada	Edible and inedible	Used Statistics Canada and USDA data to develop estimate	Indirect				54.5	121.5	
Bernstad <i>et al.</i> (2012)	2008	Sweden	Edible and inedible	Weighing all waste leaving the study area and repeated waste composition analyses of large samples from all fractions	Direct					95.7	
Bernstad <i>et al.</i> (2013)	2009	Sweden	Edible and inedible	Weighing of all waste fractions, repeated waste composition analyses of disposed waste and a questionnaire	Direct					68.8	
Brautigam <i>et al.</i> (2014)	2006	EU	Edible and inedible	Calculations are based on a FAO mass flow methodology (based on Food Balance Sheets, described in Gustavsson <i>et al.</i> , 2011, 2013)	Indirect	95.2	30.6	33.5	14.4	114.8	288.5
Buzby and Hyman (2012)	2008	USA	Edible	Compiled estimates of food loss using the USDA ERS's (2014) <i>Loss-Adjusted Food Availability</i> (LAFAs) data	Indirect					188.0	
Buzby <i>et al.</i> (2014)	2010	USA	Edible	Compiled estimates of food loss using the USDA ERS's (2014) LAFAs data	Indirect				63.3	195.0	
Defra (2010)	2007	England	Edible and inedible	The results from various curbside and recycling depot waste audits were summarised to develop an estimate of waste quantity and composition, including food waste	Direct					83.2	
EC (2010)	2006	EU	Edible and inedible	Used 2006 Eurostat data and various national sources to compile total food waste per country	Indirect			70.0	33.9	75.9	179.8
Edjabou <i>et al.</i> (2015)	2013	Denmark	Edible and inedible	A waste auditing methodology was developed and used to estimate the composition, including food waste, of curbside single family and multi residential waste	Direct					86.6	
Edjabou <i>et al.</i> (2015)	2013	Denmark	Edible and inedible	A waste auditing methodology was developed and used to estimate the composition, including food waste, of curbside single family and multi residential waste	Direct					75.3	
Garrone <i>et al.</i> (2014)	Not provided	Italy	Edible and inedible	Case studies were used to develop an extrapolated estimate of the amount of food waste generated from food processing and distribution/retail sales in Italy	Indirect			3.0	13.0		
Griffin <i>et al.</i> (2009)	1999	USA	Edible and inedible	A case study was conducted in a single upper New York State County to estimate food waste generation along the FSC. Information was gathered through interviews and from published county, state and national sources	Indirect	19.3		1.2	17.6	57.6	95.6
Gustavsson <i>et al.</i> (2011)	2007	North America and Oceania	Edible	Used FAO datasets and assumptions to address data gaps to develop estimates of FLW along the FSC	Indirect					115.0	300.0
Gustavsson <i>et al.</i> (2011)	2007	Europe	Edible	Used FAO datasets and assumptions to address data gaps to develop estimates of FLW along the FSC	Indirect					95.0	280.0
Hodges <i>et al.</i> (2010)	2008	USA	Edible	Used 2008 USDA ERS, data to develop an estimate of food waste	Indirect				64.0	123.8	

(continued on next page)

Table 1. Continued

Author	Year	Country/region	State of food	Method	Study methodology	Food supply chain: (kg/capita)/year					Total
						Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption	
Jones (2006)	Not provided	USA	Edible and inedible	No explanation of methods						213.6	
Jones (2005)	Not provided	USA	Edible and inedible	No explanation of methods				106.4			296
Kantor <i>et al.</i> (1997)	1995	USA	Edible and inedible	The USDA ERS (2014) developed preliminary estimates of food waste generation by retail, food service and consumer sectors. Many of the studies on which these estimates are based date from the mid-1970s or before	Indirect			9.3		155.0	266.3
Katajajuuri <i>et al.</i> (2014) and Silvennoinen <i>et al.</i> (2014)	2010	Finland	Edible	Household food waste data was collected through a diary study. Food service sector data was collected by way of on site (i.e. weighing of food waste along various parts of food service chain – for example, cooking, serving, customer leftovers). Retail sector and industry data was collected by way of interviews of various parties in the supply chain	Direct			14.0–26.0	26.0–30.0		23.0
Langley <i>et al.</i> (2010)	Not provided	UK	Edible and inedible	Tested a method of quantifying (self-weighing) and estimating the composition (through use of a diary) of food waste disposed by households	Direct						72.6
Lebersorger and Schneider (2011)	2009	Austria	Edible and inedible	Calculated the number (n) of urban and rural waste samples to collect and sort on the basis of a 95% confidence level, using mean and standard deviation (SD) data from previous waste analyses	Direct						49.6
Lebersorger and Schneider (2011)	2009	Austria	Edible and inedible	Calculated the number (n) of urban and rural waste samples to collect and sort on the basis of a 95% confidence level, using mean and SD data from previous waste analyses	Direct						18.8
Matsuto and Ham (1990)	1989	USA	Edible and inedible	Waste samples collected from curb in Madison, Wisconsin and Sapporo, Japan and manually sorted into a number of categories, including food waste	Direct						65.3
Matsuto and Ham (1990)	1988	Japan	Edible and inedible	Waste samples collected from curb in Madison, Wisconsin and Sapporo, Japan and manually sorted into a number of categories, including food waste	Direct						123.0
Okazaki <i>et al.</i> (2008)	2005	Hawaii, USA	Edible and inedible	Information collected on food establishments and their practices came from the State of Hawaii Department of Health list of permitted food establishments and a food waste recycling survey was developed and distributed to all permit holders	Direct			240.9			
Parizeau <i>et al.</i> (2015)	2015	Canada	Edible and inedible	Data from green bin only and did not include household garbage destined for landfill. Also allowable green bin items include other items besides food waste	Direct						217.4
USDA ERS (2014)	2010	USA	Edible and inedible	Compiled estimates of food loss using the USDA ERS's (2014) LAFA data	Indirect						194.9

(continued on next page)

Table 1. Continued

Author	Year	Country/region	State of food	Method	Study methodology	Food supply chain: (kg/capita)/year					Total
						Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption	
USEPA (2009)	2008	USA	Edible and inedible	USEPA collects and reports on waste generation and disposal data in the USA and has done so for the last 30 years. Municipal solid waste (MSW) includes household, commercial and institutional waste	Indirect						104.5
USEPA (2014)	2012	USA	Edible and inedible	USEPA collects and reports on waste generation and disposal data in the USA and has done so for the last 30 years. MSW includes household, commercial and institutional waste	Indirect						116.0
WRAP (2009)	2007	UK	Edible and inedible	Estimates of solid and liquid food waste were derived from annual waste generation totals obtained from municipalities, waste composition studies and diary research	Direct						134.3
WRAP (2013b)	2011	UK	Edible and inedible	Gathered production and retail data and applied estimates of food waste to develop estimates. Developed a mass balance to estimate food waste types and how are they are managed	Direct	61.7	7.1				
WRAP (2013a)	2012	UK	Edible and inedible	The estimates for household food and drink waste were derived from a summary of waste audits and kitchen diary research	Direct						130.3

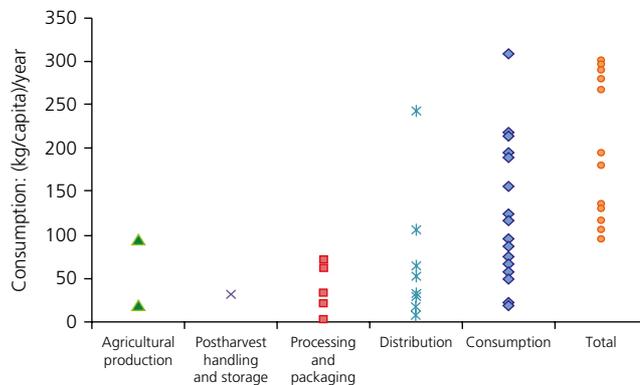


Figure 3. Detail of FLW weight data points across the FSC

data and previous studies that estimated FLW generation. The higher estimates identified in the review were from the US state of Hawaii (Okazaki *et al.*, 2008) (240.9 (kg/capita)/year) (survey). The ‘agricultural production’ to ‘distribution’ parts of the FSC represent pre-consumer FLW estimates. Estimates ranged from 173.7 to 185.0 (kg/capita)/year (Brautigam *et al.*, 2014; Gustavsson *et al.*, 2011).

3.2.4 Consumption

In this review, the most data points and highest average annual per capita FLW generation (114.3 (kg/capita)/year) are found within the ‘consumption’ part of the FSC. The lower estimates came from a rural area (Lebersorger and Schneider, 2011) (18.8 (kg/capita)/year) (based on waste audit of curb-side waste samples) and Finland (Katajajuuri *et al.*, 2014; Silvennoinen *et al.*, 2014) (23 (kg/capita)/year) (based on diary study that measured edible food waste only). The highest estimate came from Canada (308 kg/capita) (Abdulla *et al.*, 2013) (using Statistics Canada and World Bank data and applying USDA waste factors).

3.2.5 Total

In some cases, estimates of ‘total’ FLW included the sum of FLW estimates from the different parts of the FSC, but in most cases this was characterised by standalone estimates of all FLW generated. On average it was estimated that 198.9 (kg/capita)/year of FLW is generated. The lower estimates came from a single upstate New York State county (Griffin *et al.*, 2009) (95.6 (kg/capita)/year) (case study) and the USA (USEPA, 2014) (116 (kg/capita)/year). The highest estimate was based on studies of North America and Oceania (300 (kg/capita)/year) (Gustavsson *et al.*, 2011).

3.3 Review of independent variables

Table 3 presents a summary of average FLW for the independent variables: (a) scope of FLW (inedible/edible or edible),

Table 2. Summary of FLW weight data points across FSC ((kg/capita)/year)

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution	Consumption	Total
<i>n</i>	2	1	5	11	24	12
Min.	19.3	30.6	1.2	7.1	18.8	95.6
Max.	95.2	30.6	70.0	240.9	308.2	300.0
Average	57.2	30.6	33.9	56.7	114.3	198.9
SD	53.7	—	32.0	68.5	68.7	82.3

Table 3. Summary of independent variables and FLW weight data points ((kg/capita)/year) for the dependent variables: 'distribution', 'consumption' and 'total'

	Scope of FLW		Geography		Study methodologies	
	Inedible/edible	Edible	Europe	North America	Indirect	Direct
<i>Distribution</i>						
<i>n</i>	9	3	5	7	8	3
Average	55.2	51.7	19.3	79.4	33.7	92.0
SD	76.9	20.5	11.2	78.2	23.5	129.4
<i>p</i>	0.940	—	0.123	—	0.517	—
<i>Consumption</i>						
<i>n</i>	18	6	12	11	11	12
Average	111.0	123.3	71.6	160.0	140.9	81.6
SD	71.7	63.6	28.7	73.8	69.7	51.6
<i>p</i>	0.719	—	0.003	—	0.030	—
<i>Total</i>						
<i>n</i>	10	2	5	7	9	2
Average	180.6	290.0	202.6	196.2	202.9	132.3
SD	77.7	14.1	77.1	91.8	83.7	2.8
<i>p</i>	0.085	—	0.902	—	0.035	—

(b) geography (Europe or North America) and (c) study methodologies (direct or indirect measurement), for the dependent variables: 'distribution', 'consumption' and 'total'. The FLW differences of greatest magnitude were related to the variables geography and study methodologies. For geography, the average FLW estimates for 'distribution' were higher and 'consumption' significantly higher ($p = 0.003$) for North America than Europe although for 'total' they were similar. For study methodologies, direct measurement methods ($n = 3$) resulted in higher FLW estimates for 'distribution'. Indirect measurements resulted in significantly higher FLW estimates for 'consumption' ($p = 0.030$) and 'total' ($p = 0.035$), although it should be noted that for there were only two studies that employed direct study methodologies to estimate 'total' FLW.

3.4 Risk of bias within and across studies

The main risk of bias within the studies reviewed relates to how data were collected and analysed. For studies using indirect measurement the risk of bias relates to what is actually being measured. The general approach is to use estimates of the amount of food that is produced and apply estimates of FLW along the various parts of the FSC. These estimates are

generally old (some date to the mid-1970s) and it is not clear how they were developed. The risk of bias, across studies, occurs when this same methodology or variation thereof is used by a number of researchers. Any under- or over-estimation could also be manifested in these studies.

For studies using direct measurements involving the collection and sorting of waste samples, the risk of bias relates to the representativeness of the samples (e.g. number and location of households from which waste is collected for composition analysis) and the meaningfulness of resultant extrapolations. For direct food waste measurements that involve self-reporting (e.g. using diaries) the risk of bias relates to the lack of blinding. Mindful that different interventions are not being assessed in these studies; bias can be manifest as performance and detection bias. There appeared to be little risk of bias across these studies because the methodologies did not appear to be shared.

4. Discussion

The results showed that there is a greater tendency to measure FLW at or just before it gets to the consumer and that these

yield the highest estimates; that there is considerable variability in the data; that North American estimates are generally higher than European ones; and that indirect measurements generally result in higher FLW estimates. The results are far from unequivocal and this exercise confirms the noted concerns about the current state of FLW data and methodological issues (Abdulla *et al.*, 2013; Gustavsson *et al.*, 2011; Langley *et al.*, 2009; Parfitt *et al.*, 2010).

4.1 Methodological issues

A key methodological issue is that FLW estimates are derived both indirectly and directly, yielding results that are difficult to compare. Furthermore, current estimates do not always differentiate edible from inedible FLW or offer much detail on its composition. Indirect estimates are often used to develop global, continent or country wide estimates whereas direct measurements are used for smaller geographic units such as a city or a region (Table 1). Table 4 summarises the differences between indirect and direct FLW measurement.

4.1.1 Indirect measurement

Indirect estimates have been derived from estimates of how much food is available to be consumed and applying waste factors.

4.1.1.1 WORLDWIDE ESTIMATES

In their widely cited paper, Gustavsson *et al.* (2011) present global and regional (Europe, North America and Oceania, Industrialised Asia, Sub-Saharan Africa, North Africa, west and central Asia, south and southeast Asia and Latin America) FLW estimates on behalf of the FAO. A mass flows model was used to estimate FLW along each part of the FSC.

The production volumes for all commodities were collected from the 2009 *FAO Statistical Yearbook* (FAOSTAT, 2010a) and the 2007 *FAO Food Balance Datasheets* (FAOSTAT, 2010b). Allocation and conversion factors were applied to determine food available for human consumption. The authors made assumptions and estimates based on FLW in similar regions and other factors where there were data gaps. There is insufficient data presented on how estimated/assumed FLW percentages across the FSC of each region were derived.

4.1.1.2 USA ESTIMATES

Countrywide estimates of American FLW data were developed by the USDA ERS (2014) starting with Kantor *et al.* (1997) to the most recent estimates by Buzby *et al.* (2014). USDA ERS (2014) provides some insights into how these estimates were developed, how they have been improved, as well as their limitations. The basis of these estimates was derived from the ERS's *Loss-Adjusted Food Availability* (LAFA) data series. It uses ERS's food availability data, which estimates the annual production of more than 200 foods and then adjusts for food spoilage, plate waste and other losses at different stages along the food supply and consumption chain, to more closely approximate actual consumption. Food loss coefficients were gathered from published reports and discussions with commodity experts. Loss assumptions were based on data and studies from the mid-1970s onwards.

As described in USDA ERS (2014), attempts have been made to improve the underlying assumptions used to make estimates of FLW. Estimates of primary level (i.e. farm to retail weight) FLW were updated through industry interviews and research. Some retail FLW estimates were updated by comparing

Table 4. Comparison of indirect and direct measurement of FLW

	Indirect measurement	Direct measurement
General approach	Mass flows model used to estimate FLW at a specific FSC position(s)	Direct collection of waste samples to estimate FLW at a specific FSC position(s)
Steps to calculate FLW	<p>FLW estimated using five-step process</p> <ul style="list-style-type: none"> ■ Estimate production volumes (typically national or transnational), per commodity ■ Estimate food loss coefficient, per commodity ■ Calculate the product of the production volume and food loss coefficient, per commodity ■ Allocate FLW across the FSC, per commodity ■ Sum per commodity FLW to develop total per FSC position FLW 	<p>FLW estimated using six-step process</p> <ul style="list-style-type: none"> ■ Scope by position on FSC, where waste samples will be collected ■ Scope by geography (e.g. city) ■ Scope by FLW sorting categories (e.g. edible and inedible) ■ Collect representative samples of FLW ■ Manually sort and weigh FLW into selected categories ■ Extrapolate FLW by scoped position(s) on the FSC, geography and sorting categories
Output	Results in general national and transnational FLW estimates	Results in specific and geographically scoped local FLW estimates
Using data	Identifies and estimates extent of FLW but offers little 'empirical' evidence on where to possibly implement interventions	Identifies and estimates extent of local FLW and offers 'empirical' evidence on where to possibly implement interventions

supplier shipment data with point of sales data at large national supermarket chains and supplemented with qualitative information from retail contacts. Consumer-level loss estimates for cooking loss and food loss from edible food were updated through: (a) a review of the literature, (b) a small set of restaurant interviews, (c) a numerical estimation method to calculate consumer-level food loss estimates using Nielsen Homescan data (food purchase data) and (d) the dietary intake component of the National Health and Nutrition Examination Survey (food consumption data). In 2012, ERS used the 'best estimate' of these consumer FLW estimates, but continued to use the LAFA dataset when updated data was unavailable.

The LAFA dataset does not measure actual consumption or quantities ingested because it is not based on direct observations of individual intake. Furthermore, LAFA does not identify where, along the FSC, FLW is created. Ultimately, these estimates function as a proxy of per capita consumption and FLW generation along the FSC.

4.1.1.3 CANADIAN ESTIMATES

Abdulla *et al.* (2013) used reports published from Statistics Canada and the World Bank to calculate FLW from food available for consumption. Statistics Canada used 'waste factors' provided by the USDA (Statistics Canada, 2010) to estimate FLW at the consumption part of the FSC. Canada does not have the data required to empirically quantify FLW at each point in the FSC. Abdulla *et al.* (2013) recommends launching a replicable pilot study in an area or region to measure FLW across the FSC and then replicate elsewhere in Canada.

4.1.2 Direct measurement

Direct measurements of FLW are taken where it is possible to collect and sort waste samples. To date, this has tended to occur with post-consumer waste and specifically at the 'consumption' part of the FSC.

4.1.2.1 UK

The UK's Waste Reduction Action Programme (WRAP, 2009, 2013a, 2013b) has developed a number of solid and liquid 'consumption' estimates of FLW. This relies on waste management tonnage data collected by local authorities, the results of waste composition analysis (i.e. waste audits) and use of kitchen diaries (i.e. FLW tracking by residents). It multiplies the percentage of FLW in the waste stream with the total amount of waste generated and supplements this with waste composition data and with kitchen diary data (i.e. which also included detail on pet feeding or home composting of FLW).

'Processing and packaging' and 'distribution' data were obtained from various industry surveys (i.e. by the

Environment Agency, Department for Environment, Food and Rural Affairs (Defra), Food and Drink Federation), business reports on waste (to satisfy permitting requirements) and using business register data to estimate and extrapolate waste generation. FLW estimates were developed from a variety of datasets, because individual datasets did not provide a complete set of information.

4.1.2.2 OTHER

Some studies used direct measurement to either estimate and/or test methods to estimate FLW generation (Katajajuuri *et al.*, 2014; Langley *et al.*, 2010; Lebersorger and Schneider, 2011; Okazaki *et al.*, 2008; Parizeau *et al.*, 2015; Silvennoinen *et al.*, 2014) or to assess the impacts of FLW reduction interventions (Bernstad *et al.*, 2012, 2013). Studies typically included a weight-based assessment of FLW and in some cases included diary studies or surveys. For other studies the focus was on estimating the composition of the overall waste stream of which FLW was a component (Defra, 2010; Edjabou *et al.*, 2015; Matsuto and Ham, 1990). The challenge with the direct measurement of FLW is the ability to extrapolate the resultant data. WRAP (2009, 2013a, 2013b) and Defra (2010) have demonstrated a possible methodological approach.

4.2 Additional research

Given the challenges described for using indirect sampling it is difficult to envision its use for developing anything more than a general picture of the current situation, but not to inform the development of interventions in any meaningful way. Direct measurement of FLW, from collected waste samples, should result in more precise estimates of FLW, at least for the geographic area in which they were completed. This data can be used to inform intervention development and importantly can subsequently be re-measured to assess the efficacy of the intervention.

Additional research is required to better understand FLW generation across all parts of the FSC. To date FLW estimates have focused on 'consumption' and to a lesser extent 'distribution' and 'total' estimates. Additional FLW estimates are required for 'agricultural production', 'postharvest handling/storage' and 'processing and packaging'. Although challenging, particularly for 'agricultural production', where in-field or in-barn measurements would be necessary, direct measurements should be taken to develop these estimates. Furthermore, FLW estimates from 'agricultural production' require a more precise definition to determine when food becomes FLW. For instance, there may be in-field sorting of a crop whereby a portion of the crop is left behind in the field. While this could be construed to be FLW it could also be considered as a source of organic matter necessary to maintain soil tilth.

Additional methodological development to directly measure FLW across the FSC are required as initiated by Langley *et al.* (2010) and Lebersorger and Schneider (2011) with the possible enhancement of these estimates through mathematical methods (Langley *et al.*, 2009). The basis of these methods should focus on statistically sound weight-based assessment of waste samples, through waste auditing but also provide additional detail on the various food fractions (e.g. bakery, meat) that make up FLW. As well, it should include consideration of edible against inedible FLW because this can help establish the net amount that is recoverable for human consumption. These methods should be tested and refined in small geographic areas (e.g. cities and towns). Ultimately, the results of FLW estimates from small geographic areas can be assembled and extrapolated to develop broader regional (e.g. province) or countrywide FLW estimates.

Efforts to add more rigour to FLW measurement are underway and include *The Food Loss and Waste Accounting and Reporting Standard* (FLW Protocol, 2016). Although largely neutral on indirect and direct methods, it presents a detailed and systematic framework on how to approach FLW measurement, so that it meets the needs to those measuring FLW and facilitating potential comparison of results.

4.3 Limitations

This review only looked at weight-based FLW estimates and did not consider GHG, calorie- or dollar-based FLW estimates for two reasons. First, this was the most common FLW estimation approach, by far. Second, these other metrics are largely inferred from weight-based estimates and given the above noted FLW estimation challenges this was deemed to be of limited value.

4.4 Conclusions

Based on this systematic review of the literature, 'total' average FLW in developed countries is estimated to be 198.9 (kg/capita)/year, while average 'consumption' related FLW is estimated to be on average 114.3 (kg/capita)/year. There is considerable variability in the various FLW estimates and this is a function of how this data has been collected, and in particular, if the data was collected indirectly or directly. While indirect measurements can provide an overview of the current situation, direct measurements are needed to develop more accurate and precise estimates of FLW, as well as its composition. Ultimately, what is required is the development and testing of a bespoke and statistically sound methodology to directly measure FLW. This method should be developed so that it is replicable and usable in a variety of geographic contexts (e.g. city, region). While global or countrywide FLW estimates developed through indirect data collection are interesting, more scoped estimates will provide improved data from which purpose-built interventions to reduce FLW can be developed and implemented.

Acknowledgement

The authors thank Dr Jamie Seabrook, Associate Professor, School of Food and Nutritional Sciences Brescia University College, Western University for providing statistical assistance.

REFERENCES

- AAFC (Agriculture and Agrifood Canada) (2015) *An Overview of the Canadian Agriculture and Agri-Food System*. AAFC, Ottawa, Canada.
- Abdulla M, Martin RC, Gooch M and Jovel E (2013) The importance of quantifying food waste in Canada. *Journal of Agriculture, Food Systems, and Community Development* **3**(2): 137–151.
- Alexandratos N and Bruinsma J (2012) *World Agriculture Towards 2030/2050: The 2012 Revision*. FAO, Rome, Italy, ESA working paper No. 12-03.
- Beretta C, Stoessel F, Baier U and Hellweg S (2013) Quantifying food losses and the potential for reduction in Switzerland. *Waste Management* **33**(3): 764–773.
- Bernstad A, La Cour Jansen J and Aspegren H (2012) Local strategies for efficient management of solid household waste—the full-scale Augustenborg experiment. *Waste Management and Research* **30**(3): 200–212.
- Bernstad A, Jansen JL and Aspegren A (2013) Door-stepping as a strategy for improved food waste recycling behaviour evaluation of a full-scale experiment. *Resources Conservation and Recycling* **73**: 94–103.
- Brautigam KR, Jorissen J and Priefer C (2014) The extent of food waste generation across EU-27: different calculation methods and the reliability of their results. *Waste Management and Research* **32**(8): 683–694.
- Buzby JC and Hyman J (2012) Total and per capita value of food loss in the United States. *Food Policy* **37**(5): 561–570.
- Buzby JC, Wells HF and Hyman J (2014) *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States EIB-121*. US Department of Agriculture, Economic Research Service, Washington, DC, USA.
- Defra (Department for Environment, Food and Rural Affairs) (2010) *A Review of Municipal Waste Component Analyses*. Defra, London, UK.
- EC (European Commission) (2010) *Preparatory Study on Food Waste Across EU 27*. European Commission, Paris, France, Technical Report 2010-054.
- Edjabou ME, Jensen MB, Gotze R *et al.* (2015) Municipal solid waste composition: sampling methodology, statistical analyses, and case study evaluation. *Waste Management* **36**(1): 12–23.
- FAO, IFAD and WFP (Food and Agriculture Organization, International Fund for Agricultural Development and World Food Programme) (2015) *The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress*. FAO, IFAD and WFP, Rome, Italy.
- FAOSTAT (Food and Agriculture Organization Statistics) (2010a) *FAO Statistical Yearbook, – Agricultural Production*. FAOSTAT, Rome, Italy. See http://www.fao.org/docrep/014/am079m/am079m00.htm-Contents_en (accessed 07/04/2017).
- FAOSTAT (2010b) *Food Balance Sheets 2007*. FAOSTAT, Rome, Italy.
- FLW Protocol (Food Losses and Waste Protocol) (2016) *Food Loss and Waste Accounting and Reporting Standard, Version 1*. FLW Protocol, Washington, DC, USA. See http://www.wri.org/sites/default/files/FLW_Standard_final_2016.pdf (accessed 07/04/2017).
- Garrone P, Melacini M and Perego A (2014) Surplus food recovery and donation in Italy: the upstream process. *British Food Journal* **116**(9): 1460–1477.

- Griffin M, Sobal J and Lyson TA (2009) An analysis of a community food waste stream. *Agriculture and Human Values* **26**(1–2): 67–81.
- Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R and Meybeck A (2011) Global food losses and food waste: extent, causes and prevention. *Study Conducted for the International Congress SAVE FOOD! at Interpack 2011, Düsseldorf, Germany*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Gustavsson J, Cederberg C, Sonesson U and Emanuelsson A (2013) *The methodology of the FAO study: "Global Food Losses and Food Waste—extent, causes and prevention"*—FAO, 2011. The Swedish Institute for Food and Biotechnology (SIK), Göteborg, Sweden.
- Hodges RJ, Buzby JC and Bennett B (2010) Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *Journal of Agricultural Science* **149**(S1): 1–9.
- Jones TW (2005) Analyzing retail food loss. *BioCycle* **46**(12): 40–42.
- Jones TW (2006) Food loss and the American household. *BioCycle* **47**(3): 28.
- Kantor LS, Lipton K, Manchester A and Oliveira V (1997) Estimating and addressing America's food losses. *Food Review* **20**(1): 2–12.
- Katajajuuri JM, Silvennoinen K, Hartikainen H, Heikkilä L and Reinikainen A (2014) Food waste in the Finnish food chain. *Journal of Cleaner Production* **73**: 322–329.
- Koester U (2013) Total and per capita value of food loss in the United States – comments. *Food Policy* **41**: 63–64.
- Koester U (2014) Food loss and waste as an economic and policy problem. *Intereconomics* **49**(6): 348–354.
- Kummu M, de Moel H, Porkka M et al. (2012) Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment* **438**: 477–489.
- Langley J, Yoxall A, Manson G et al. (2009) The use of uncertainty analysis as a food waste estimation tool. *Waste Management and Research* **27**(3): 199–206.
- Langley J, Yoxall A, Heppell G et al. (2010) Food for thought? A UK pilot study testing a methodology for compositional domestic food waste analysis. *Waste Management and Research* **28**(3): 220–227.
- Lebersorger S and Schneider F (2011) Discussion on the methodology for determining food waste in household waste composition studies. *Waste Management* **31**(9–10): 1924–1933.
- Liberati A, Altman DG, Tetzlaff J, Mulrow C and Gotzsche PC (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med* **6**(7): e1000100.
- Matsuto T and Ham RK (1990) Residential solid waste generation and recycling in the U.S.A. and Japan. *Waste Management and Research* **8**(3): 229–242.
- Nahman A and de Lange W (2013) Costs of food waste along the value chain: evidence from South Africa. *Waste Management* **33**(11): 2493–2500.
- Nellemann C, MacDevette M, Manders T et al. (eds) (2009) *The Environmental Food Crisis – The Environment's Role in Averting Future Food Crises*. A UNEP Rapid Response Assessment, GRID-Arendal.
- Okazaki WK, Turn SQ and Flachsbarth PG (2008) Characterization of food waste generators: a Hawaii case study. *Waste Management* **28**(12): 2483–2494.
- Parfitt J, Barthel M and MacNaughton S (2010) Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**(1554): 3065–3081.
- Parizeau K, von Massow M and Martin R (2015) Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. *Waste Management* **35**: 207–217.
- Petticrew M and Roberts H (2006) *Systematic Review in the Social Sciences – A Practical Guide*. Blackwell Publishing, Malden, MA, USA.
- Schneider F (2013) Review of food waste prevention on an international level. *Proceedings of the Institution of Civil Engineers – Waste and Resource Management* **166**(4): 187–203, <http://dx.doi.org/10.1680/warm.13.00016>.
- Silvennoinen K, Katajajuuri JM, Hartikainen H, Heikkilä L and Reinikainen A (2014) Food waste volume and composition in Finnish households. *British Food Journal* **116**(6): 1058–1068.
- Statistics Canada (2010) *Food statistics 2009 (Catalogue No. 21-020-X)*. See http://www.statcan.gc.ca/access_acces/archive.action?loc=/pub/21-020-x/21-020-x2009001-eng.pdf&archive=1 (accessed 25/04/2017).
- Tike (2010) *Balance Sheet for Food Commodities 2008 and 2009*. Tike, Helsinki, Finland.
- USDA-ERS (US Department of Agriculture-Economic Research Service) (2014) *Loss-Adjusted Food Availability Documentation*. USDA-ERS, Washington, DC, USA.
- USEPA (US Environmental Protection Agency) (2009) *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008*. USEPA, Washington, DC, USA.
- USEPA (2014) *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012*. USEPA, Washington, DC, USA.
- Viinisoalo M, Nikkilä M and Varjonen J (2008) *Elintarvikkeiden kulutusmuutokset kotitalouksissa vuosina 1966–2006*. Kuluttajatutkimuskeskus (Consumer Research Centre), Helsinki, Finland (in Finnish).
- WRAP (Waste Reduction Action Programme) (2009) *Household Food and Drink Waste in the UK*. WRAP, Banbury, UK. See http://www.wrap.org.uk/sites/files/wrap/Household_food_and_drink_waste_in_the_UK_-_report.pdf, 95 (accessed 07/04/2017).
- WRAP (2013a) *Household Food and Drink Waste in the United Kingdom 2012*. WRAP, Banbury, UK. See <http://www.wrap.org.uk/content/household-food-and-drink-waste-uk-2012>, 135 (accessed 07/04/2017).
- WRAP (2013b) *Estimates of Waste in the Food and Drink Supply Chain*. WRAP, Banbury, UK. See http://www.wrap.org.uk/sites/files/wrap/Estimatesofwasteinthefoodanddrinksupplychain_0.pdf (accessed 07/04/2017).

How can you contribute?

To discuss this paper, please email up to 500 words to the editor at journals@ice.org.uk. Your contribution will be forwarded to the author(s) for a reply and, if considered appropriate by the editorial board, it will be published as discussion in a future issue of the journal.

Proceedings journals rely entirely on contributions from the civil engineering profession (and allied disciplines). Information about how to submit your paper online is available at www.icevirtuallibrary.com/page/authors, where you will also find detailed author guidelines.