# Introduction to global food losses and food waste

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## 1.1 Introduction

Food losses and food waste (FLW) occur along the whole food supply chain. In recent years, FLW has become a global concern and poses considerable challenges to food security (The Economist Intelligence Unit, 2014), natural resources (FAO, 2013), environment (Katajajuuri et al., 2012), and human health (Pham et al., 2014), and is therefore considered as a key obstacle to sustainable development. Therefore, reducing FLW has been put on the political agenda at the global and national levels. For instance, the United Nations has set a target of halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains by 2030, in the Sustainable Development Goals (SDG) Target 12.3 (United Nations, 2017). The European Union (European Commission Food Safety Home Page, 2017) has taken actions to work towards this

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target; in 2015, the United States (United States Department of Agriculture, 2017) also announced its first-ever national goal to reduce food waste by 50% by 2030 to improve food security and protect natural resources; and the African Union also made a commitment to halve postharvest losses by 2025 in the 2014 Malabo Declaration (Lipinski et al., 2016).

Over the past few decades, with growing concerns and attention on FLW from public and political sectors, more and more studies have quantified FLW across the food supply chain at national, regional, and global scales. For example, according to the Food and Agriculture Organization (FAO) of the United Nations, about one-third of food production was lost or wasted worldwide that was meant for human consumption (Gustavsson et al., 2011). This significant amount of FLW would mean 4.4 gigatonnes of $CO_2$ equivalent (FAO, 2015), 250 $km^3$ of blue water footprint (FAO, 2013), 28% of the total agriculture land globally during agriculture production, an economic cost of about USD 750 billion (equivalent to the gross domestic product (GDP) of Turkey) (FAO, 2013), and approximately 24% of all food produced when converted into calories (Gustavsson et al., 2011).

Many other studies have also revealed a similar scale of FLW on the regional or country level and its significant impacts on environment, economic development, and food security. For example, it is reported that the EU-28 generate about 100 million tonnes of FLW each year, and the largest contribution is from households (45%) (FUSIONS, 2015). For the member states, households in the United Kingdom wasted approximately 7.2 million tonnes of food in 2012 (WRAP, 2014). The wasted food from households in Finland, Denmark, Norway, and Sweden make up 30%, 23%, 20%, and 10%−20% of food purchased, respectively (Gjerris and Gaiani, 2013). In Switzerland, about one-third of food produced (calorie equivalent) is wasted and households contribute the most (Beretta et al., 2013). Some other developed countries also highlight a similar trend. For example, in the United States, the per capita FLW increased by about 50% between 1979 and 2003 (Hall et al., 2009). In Australia, more than 4.2 million tonnes of FLW goes to landfill per year (Verghese et al., 2013).

In the past decades, some governmental organizations and national agencies have made great effort to quantify FLW. For example, the FAO has issued a number of relevant reports on FLW at a global scale (Gustavsson et al., 2011; FAO, 2014). The United States Department of Agriculture Economic Research Service (USDA-ERS) developed the Loss-Adjusted Food Availability Data Series in 1997, which covers about 200 items for three stages (production to retail, retail, and consumer) of losses in terms of quantities, values, and calories (Buzby et al., 2009; Buzby and Guthrie, 2002). In the United Kingdom, the Waste and Resources Action Programme (WRAP) organization has been set up to reduce food waste, and has released a number of reports on FLW in the food supply chain since 2007 (WRAP, 2008, 2009).

In recent years, relevant stakeholders from academia, industry, and governmental and nongovernmental organizations have participated in research projects and worked on the standardization of quantification and methods of FLW. For example, the project Food Use for Social Innovation by Optimizing Waste Prevention

Strategies (FUSIONS) (2012−16) funded by European Commission has been working towards a more resource efficient Europe, and has issued a number of reports, covering the framework of FLW definition, measurement, and mitigation strategies (Östergen et al., 2014; FUSIONS, 2016). In 2015, the European Commission funded a further project called Resource Efficient Food and dRink for the Entire Supply cHain (REFRESH) (2015−19), which involves 26 partners from 12 European countries and China and focuses on the reduction of avoidable waste and improved valorization of food resources (Refresh Home Page, 2017). In 2016, World Resources Institute, United Nations Environment Programme (UNEP), World Business Council for Sustainable Development, FAO, and WRAP together as a partnership of major international organizations announced the first global standard to quantify FLW (World Resources Institute, 2016).

Though there are continuous efforts on quantifying FLW and some researchers have also stressed the data deficiency and inconsistency and raised concerns on the demand of better measurement of FLW (Parfitt, 2013; Liu, 2014; Shafiee-Jood and Cai, 2016), there are still major gaps in the existing global FLW data as follows:

- The spatial coverage of existing studies is narrow. Most research is carried out in developed countries. For instance, there are plenty of publications drawing out the situation of FLW in the United States (Thyberg et al., 2015; Buzby and Hyman, 2012; Kantor et al., 1997) and Sweden (Bräutigam et al., 2014; Filho and Kovaleva, 2015). In contrast, only a few studies quantified FLW in developing countries, such as Nepal (Choudhury, 2006) and the Philippines (Parfitt et al., 2010) and some countries experiencing a rapid development, such as China and India (Parfitt and Barthel, 2011).
- There is an uneven focus on the different food supply stages. A great many studies have illustrated food waste at retailing and consumption stages (Davies and Konisky, 2000; Stenmarck et al., 2011; Parry et al., 2015), mainly conducted in developed countries, such as the United States. On the other hand, there are few studies revealing the situation of postharvest losses, which are mainly carried out in developing countries, such as India (Gangwar et al., 2014).
- Some existing data are outdated but still in use. Some studies have to depend on the older data due to the lack of updated ones. For example, data on the postharvest losses of fresh fruits and vegetables from one study in the 1980s and 1990s were used in two recent studies (Parfitt et al., 2010; Kader, 2005).
- There is a lack of primary data and a great many studies have to cite data in the existing studies. For example, many researchers have repeatedly cited data from the FAO report issued in 2011 (Oelofse and Nahman, 2013; Lipinski et al., 2013; Nahman and de Lange, 2013). But it may not be representative in terms of time and countries for commodities (Liu, 2014). The data provided by the African Postharvest Loss Information System has been mostly used to address postharvest losses (Prusky, 2011; World Bank, 2011; Segrè et al., 2014).
- The definition of FLW, methods used, and system boundaries are different in existing studies. This makes it difficult to systematically compare and verify FLW data between countries, commodities, and stages. Therefore, it is uncertain to do analysis on the relationship between FLW and social, economic, and environmental factors based on the existing data.

It is particular of importance to clearly and comprehensively understand the existing global FLW data on their quality and availability. First, it is a prerequisite

for tracking the progress toward the SDG Target 12.3 and the national FLW reduction goals, and evaluating the effect of relevant policies. Second, it will contribute to raising awareness, informing mitigation strategies, and giving priority to prevent and reduce FLW. Third, better data can been verified and compared among countries, stages, and commodities, helping to distinguish patterns and drivers of FLW generated. Fourth, it can be an essential foundation for further analyzing the social, economic, and environmental impacts of FLW.

In this chapter, a critical overview of all the available FLW data in 202 publications is provided, which could provide a basic database for further analysis of environmental impacts and mitigation strategies of FLW. Bibliometric characteristics of existing literature and methods of measurement (advantages and disadvantages) are assessed, their patterns between countries, food supply chain stages, and food commodities are discussed, and some implications for future work are denoted.

## 1.2 System definition

### *1.2.1 Food losses and food waste*

FLW occurs across the food supply chain. Some studies have made a difference between the definition of FLW, edible and inedible food waste, avoidable and unavoidable food waste. For example, according to the FAO (FAO, 2014), food loss refers to food that is lost due to quantity or quality reasons, and food waste refers to food that is left to spoil or expire due to carelessness of consumers, which is usually related to discarding deliberately or other use of food (e.g., animal feed). Because of the deficiency of consistencies in the literature reviewed, the distinctions were not considered and we do not differentiate between food loss and food waste in this study, so we define FLW as the combined amount of FLW.

### *1.2.2 Food supply chain*

As shown in Fig. 1.1, FLW involves six major processes. FLW could be further classified into three types: farm losses/waste (during agricultural production and harvesting), postharvest losses/waste (during postharvest handling and storage, manufacturing, distribution, and retailing), and consumer waste (both in household and out-of-home). Agricultural products losses/waste on the farm are mainly caused by insects, diseases, and severe weather. For livestock products, it relates to sickness and death during breeding stage for cattle, pig, and poultry meat, and discarded fish during fishing. Postharvest losses/waste refers to food spoilage and degradation during different stages. It includes postharvest handling and storage (when food is under threshing/shelling or icing and animals transported to slaughtering), manufacturing (when food is processed into various products), distribution (when food is transported, loaded, and uploaded), as well as retailing (includes wholesale, supermarket, and wet market). Consumer food waste occurs both in household and dining out away from home.

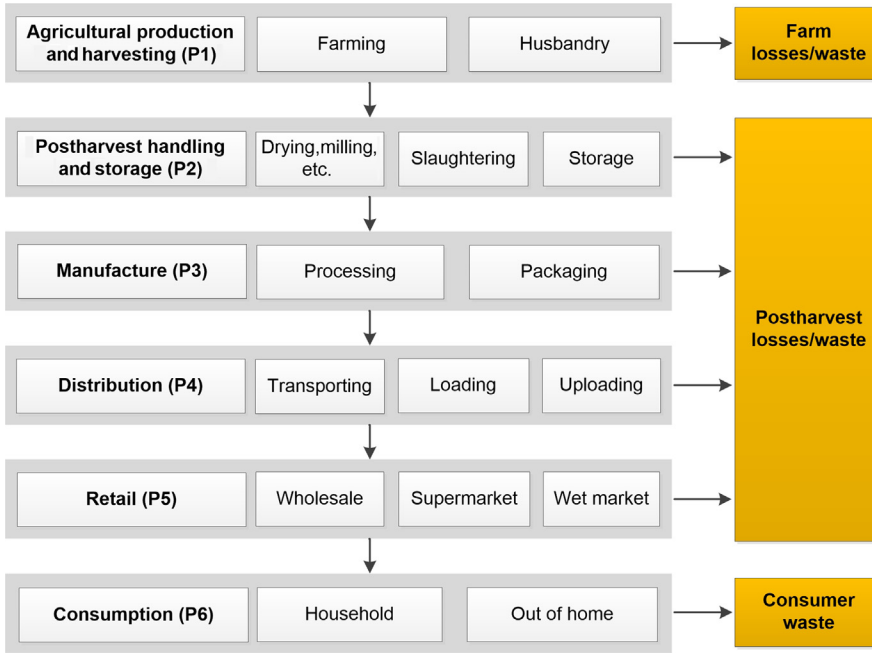


**Figure 1.1** Food supply chain for food losses and food waste.

### 1.2.3 Food commodity groups

The commodities categories were defined based on the classification of FAO and by taking consideration of characteristics of data in the publications. As a result, 10 groups of food commodities were presented:

1. Cereal and cereal products (e.g., wheat, maize, and rice);
2. Roots and tubers (e.g., potatoes and cassava);
3. Oilseeds and pulses (e.g., peanuts and soybeans);
4. Fruits;
5. Vegetables;
6. Meat;
7. Fish and seafood;
8. Dairy products;
9. Eggs;
10. Others or not specified.

### 1.2.4 Geographical and temporal boundary

The FLW data was collected from as early as possible to 2015 at the global, regional, and national levels. Based on per capita GDP and the classification principles of FAO (Gustavsson et al., 2011), the countries are divided into medium/high-income countries and low-income countries (Table 1.1).

**Table 1.1** Grouping of different development levels of countries

| **Medium/high-income countries** | | **Low-income countries** | |
|---|---|---|---|
| Armenia | Lithuania | Angola | Malaysia |
| Australia | Luxembourg | Argentina | Mexico |
| Austria | Malta | Bangladesh | Myanmar |
| Belarus | Netherlands | Benin | Nepal |
| Belgium | New Zealand | Bolivia | Nigeria |
| Bulgaria | Norway | Brazil | Pakistan |
| Canada | Poland | Cambodia | Peru |
| China | Portugal | Cameroon | Philippines |
| Cyprus | Romania | Chile | Saudi Arabia |
| Czech Republic | Russia | Colombia | South Africa |
| Denmark | Singapore | Costa Rica | Sri Lanka |
| Estonia | Slovakia | Egypt | Swaziland |
| Finland | Slovenia | Ethiopia | Tanzania |
| France | South Korea | Ghana | Thailand |
| Germany | Spain | India | Togo |
| Greece | Sweden | Indonesia | Turkey |
| Hungary | Switzerland | Iran | Uganda |
| Ireland | United Kingdom | Jamaica | Venezuela |
| Italy | Ukraine | Kenya | Vietnam |
| Japan | United States | Laos | Zambia |
| Latvia | | Madagascar | Zimbabwe |
| | | Malawi | |

## 1.3 Food losses and food waste quantification

### *1.3.1 Bibliometric analysis of literature*

#### *1.3.1.1 Type of publications*

Web of Science and Google Scholar were the main source for the research, and reports issued by research institutions as well as governmental or nongovernmental organizations were also collected to ensure a wider coverage of available data. Finally, 202 publications were reviewed. They include five types: peer-reviewed journal articles (53.5%), reports (35.6%), PhD and master's theses (5.9%), conference proceedings (3.0%), and book chapters (2.0%). Journal articles were dominant (108) in the reviewed publications, which were published in 69 different journals and covered a wide range of subjects. In total, approximately 45% of them were published in the top 10 journals (Fig. 1.2). The majority of the publications outlets were *Waste Management*, *Waste Management & Research*, *Resources, Conservation and Recycling*, *Food Policy*, and *Journal of Cleaner Production*, representing 15.7%, 7.4%, 5.6%, 4.6%, and 2.8% of the total published articles, respectively.


**Figure 1.2** The top 10 journals that publishes food loss and food waste data.

### *1.3.1.2 Temporal trend for year of publications and estimation*

Fig. 1.3A shows the number of publications during the 76-year period (1939−2015). In general, the number of publications increased throughout the whole period. It was small and remained stable before 2000. Afterwards, it has seen a gradual increase during 2001−10. In the last five years, the number of studies has grown substantially (137), accounting for 67.8% of the total publications. This means there is an increasing focus on FLW research around the world.

Fig. 1.3B illustrates the time trend of the year of estimation. According to literature, the FLW data was discovered as early as 1933, and the number remained stable and low until 1995. Afterwards, the number has increased significantly by more than 60% over the past 10 years, 38.1% from 2006 to 2010 and 25.1% from 2011 to 2014.

### *1.3.1.3 Distribution of countries*

The 202 publications reported FLW data throughout the food supply chain covering 84 countries (reported 498 times) distributed all over the world. However, the focus on FLW was unbalanced in different regions. Most studies were conducted in the developed areas, such as North America, Northern and Western Europe, whereas little attention was paid to the developing countries, such as India. Fig. 1.4 shows spatial distribution and the top 10 countries have been studied. Most research was conducted in the United Kingdom (Langley et al., 2010; Mena et al., 2014; Vanham et al., 2015; Xu et al., 2015) and United States (Thyberg et al., 2015; Buzby and Hyman, 2012; Kantor et al., 1997), both of which made up more than 10% of the reported times, respectively. Then Sweden (Bräutigam et al., 2014; Filho and Kovaleva, 2015), Germany (Kranert et al., 2012; Jörissen et al., 2015), and Finland (Silvennoinen et al., 2012; Silvennoinen et al., 2015) accounted for 5.4%, 4.4%, and 3.2%, respectively.

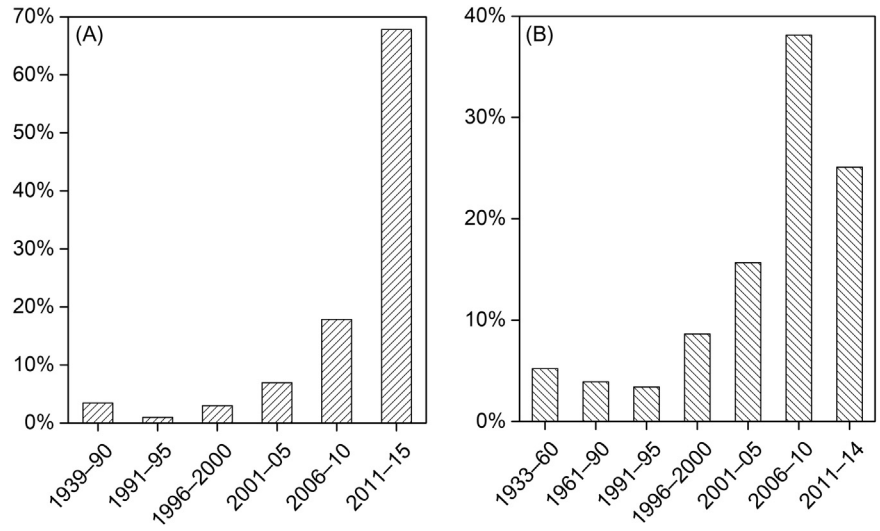


**Figure 1.3** (A) Temporal trend of reviewed food losses and food waste (FLW) data in terms of year of publication. (B) Temporal trend of reviewed FLW data in terms of year of estimation.

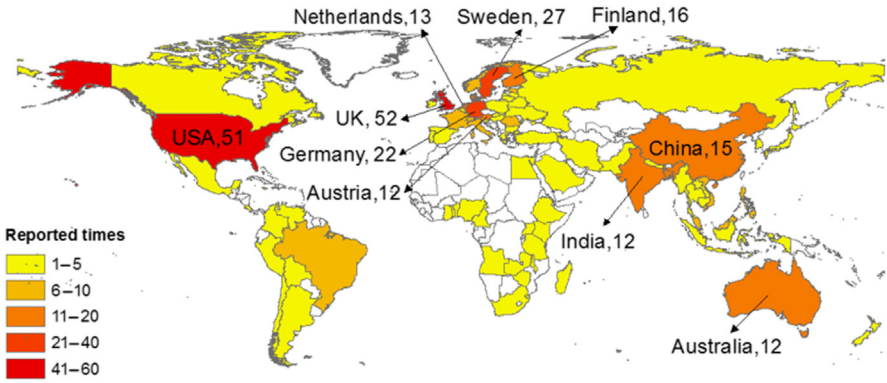


**Figure 1.4** Geographical distribution of case countries. The numbers are the reported times of individual countries.
Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

### *1.3.1.4 Food supply chain coverage*

According to the publications found, they covered different stages in the food supply chain in terms of medium/high-income countries and low-income countries. Fig. 1.5 shows that most studies covered the retailing and consumption stages. In total, the largest number of studies were carried out in household, accounting for

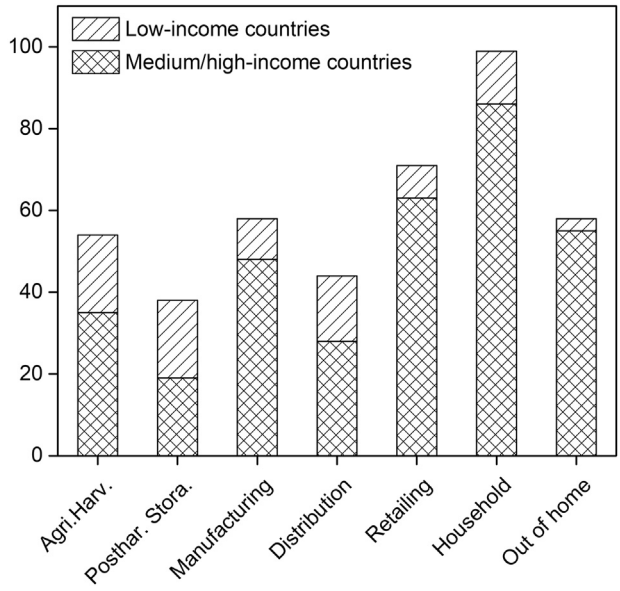


**Figure 1.5** The number of publications in terms of different food supply stages and different development levels of countries.

49% of all the publications, which was followed by the retailing stages (35%). However, only a small portion of studies included the stages between agricultural production and distribution. In detail, agricultural production, postharvest handling and storage, manufacturing, and distribution stages accounted for 26.7%, 18.8%, 28.7%, and 21.8%, respectively.

In the case of region studied, the number of publications in medium/high-income countries was much higher than that in low-income countries along the food supply chain, apart from the postharvest handling and storage stage with the same number of publications for both. The majority of studies involving retailing and consumption stages were conducted in medium/high-income countries, occupying 31.2% and 42.6% of all the literature, respectively. On the other hand, low-income countries were targeted mainly in the early and middle stages of the food supply chain, especially for the agricultural production and postharvest handling and storage stages.

## 1.3.2 Different methods used for food losses and food waste quantification

### 1.3.2.1 Overview of methods

There were various methods used to measure the quantity of FLW along the food supply chain. Table 1.2 summarizes the methods used to quantify FLW. Two kinds of methodologies have been used to quantify FLW, which can be divided into two

**Table 1.2** Description of different methods used for food losses and food waste quantification

| | Method | Symbol | Example of case countries/regions | Food supply chain | References |
|---|---|---|---|---|---|
| Direct measurement | Weighing | W | Portugal | P6b | Dias-Ferreira et al. (2015) |
| | Garbage collection | G | Austria | P6a | Dahlén and Lagerkvist (2008) |
| | Surveys | S | United Kingdom | P1, P2, P3, P5 | Mena et al. (2014) |
| | Diaries | D | United Kingdom | P6a | Langley et al. (2010) |
| | Records | R | Sweden | P5 | Scholz et al. (2015) |
| | Observation | O | Italy | P6b | Saccares et al. (2014) |
| Indirect measurement | Modeling | M | United States | P6 | Hall et al. (2009) |
| | Food balance | F | Global | P1, P2, P3, P4, P5, P6 | Gustavsson et al. (2011) |
| | Use of proxy data | P | Singapore | P6a | Grandhi and Appaiah Singh (2016) |
| | Use of literature data | L | Denmark | P1, P3, P4, P6 | Halloran et al. (2014) |

Note: P6a = Household, P6b = Out-of-home.

groups: (1) direct measurement or approximation based on first-hand data, and (2) indirect measurement or calculation derived from secondary data. These methods could provide an insight of origins and specific stages in the whole food supply chain of FLW, or an overview of FLW at the regional or global level from a macro-perspective. Detailed information on the methods used is outlined as follows:

Direct measurement involves a variety of methods to quantify or estimate the amount of FLW:

- *Weighing*: It is usually used in restaurants, hospitals, and school via instrument or device to measure the weight of FLW. It may or may not involve weighing each part of FLW for the compositional analysis.
- *Garbage collection*: This involves separation from other types of residual wastes collected to determine the weight or proportion of FLW. It may or may not involve compositional analysis of FLW. It can be collected from households (Gutiérrez-Barba and Ortega-Rubio, 2013).
- *Surveys*: Questionnaires are used to collect information about perceptions and behaviors on FLW answered by a great many individuals, or by face-to-face interviews with major stakeholders in the field. This usually takes place in households, where people can directly estimate the quantity of food waste or the percentage of food purchased that goes to waste in their families (Stefan et al., 2013).
- *Diaries*: It is often used in households and commercial kitchens by recording the quantity of FLW for a certain time, where weighing scales are sometimes used to quantify the amount of the food waste (Rathje and Murphy, 2001).
- *Records*: It is usually used in the retailing and manufacturing stages, especially for supermarkets and large-scale food companies, where regular collection of information (not initially used for FLW record) can determine the quantity of FLW.
- *Observation*: Visually estimating the amount of food left over by using scales with multiple points or assessing the volume of FLW by counting the number of goods.

The other group includes methods based on the existing data from different secondary sources:

- *Modeling*: It uses mathematical models to obtain the amount of FLW on the basis of the factors that affect FLW generation.
- *Food balance*: Using food balance sheet (e.g., FAOSTAT) based on inputs, outputs, and stocks in the food supply chain to calculate FLW, or human metabolism (e.g., the relationship between body weight and the amount of food eaten).
- *Use of proxy data*: Using data from companies or statistical institutions (in an aggregated level) to estimate the amount of FLW.
- *Use of literature data*: Using data from literature directly or estimating quantities of FLW according to the data in other literature.

Fig. 1.6 shows the methods used in the 202 publications. It can be seen that most of the publications depended on the indirect measurement (red-yellow (dark gray in print version) colors in Fig. 1.6). More than 40% of them were only based on literature data, and about one-third used other types of methods with literature data, for instance, modeling (Khan and Burney, 1989; Liu et al., 2013) or proxy data (Gooch, 2012; An et al., 2014) (indirect measurement) or weighing or surveys (Papargyropoulou et al., 2014; Edjabou et al., 2015) (direct measurement).

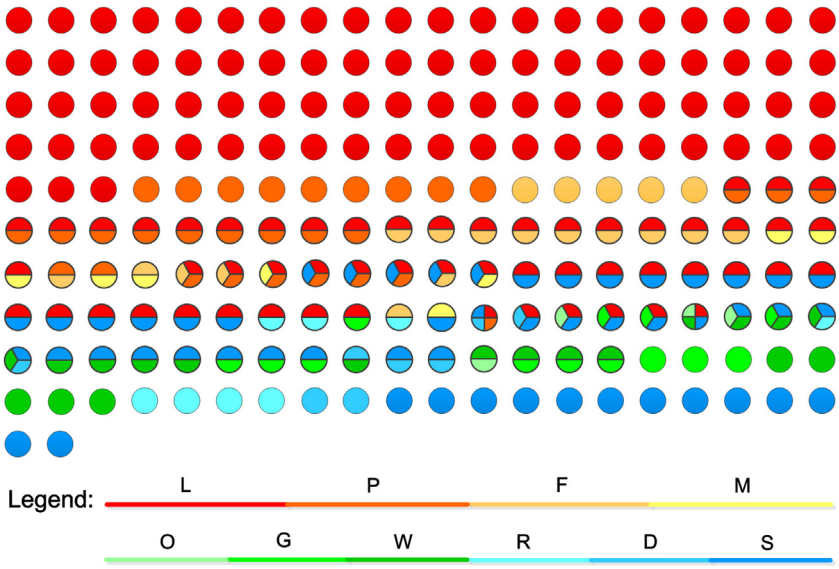


**Figure 1.6** An overview of the methods used in the reviewed 202 publications. Each circle indicates one publication, and the colors represent different methods used. Direct measurement includes: weighing (W), garbage collection (G), surveys (S), diaries (D), records (R), and observation (O). Surveys also contain questionnaires, interviews and experts' estimation. Indirect measurement involves: use of literature data (L), use of proxy data (P), food balance (F), and modeling (M).
Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

Only a small fraction of the publications depended on the direct measurement. In addition, for the 138 publications using literature data, they often depended on each other and some publications have been highly cited. More than one-fourth of them referred to the data from the top 10 publications cited, and the number of citations has greatly increased since 2008 (Fig. 1.7). The high percentage of using the secondary data may indicate that the available global FLW database has high uncertainties, especially when there is lack of original data for a certain country or a certain year but literature data that are not representative are used.

### *1.3.2.2 Advantages and disadvantages of methods*

Table 1.3 lists the advantages and disadvantages of different methods based on some criteria (e.g., time, cost, and accuracy).

- Weighing and garbage collection can provide relatively detailed, objective, and accurate information of food discarded. These two methods may lead to full quantification of FLW and can produce more detailed data at the food types level. However, they can be

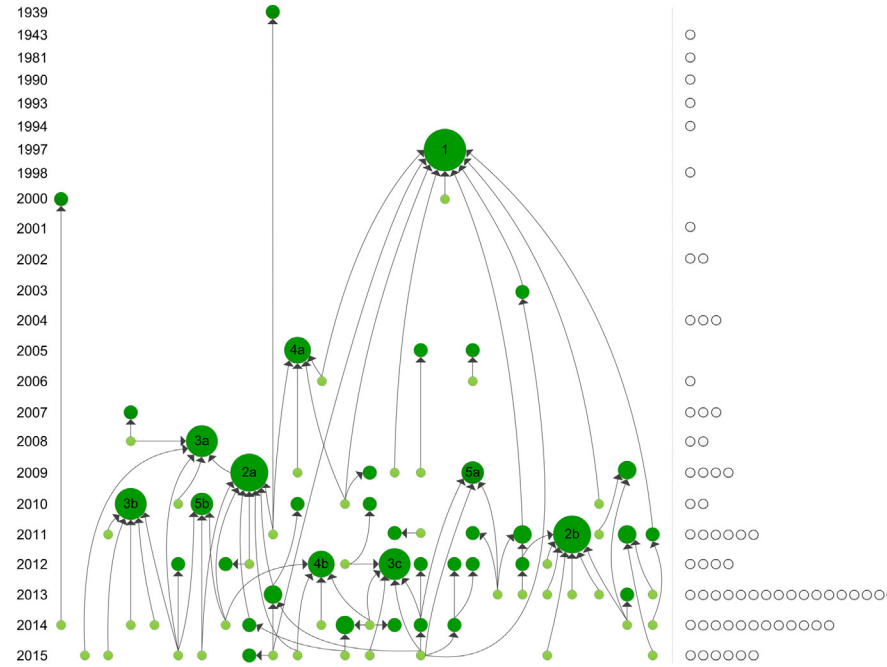


**Figure 1.7** The citation network of the 138 publications that used literature data. Each dot indicates one publication. The size of the dot represents the number of citations, and the arrow represents the direction of citation. The dots in white on the right represent publications outside the citation network. The top 10 cited publications are: (1) Kantor et al. (1997); (2a) WRAP (2009); (2b) Gustavsson et al. (2011); (3a) WRAP (2008); (3b) Monier et al. (2010); (3c) Buzby and Hyman (2012); (4a) Kader (2005); (4b) Kranert et al. (2012); (5a) Buzby et al. (2009); (5b) Langley et al. (2010).
Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

performed only when space available for classifying food and with device to weigh, and they are also more time-consuming and expensive than other methods. For example, a study on food waste in restaurants was conducted in four Chinese case cities (Beijing, Shanghai, Chengdu, and Lhasa) in 2015, which directly weighed food waste from 3557 tables in 195 restaurants of different categories, including lunch and dinner by individual items. It is estimated that food waste per capita in restaurants (approximately 11 kg/cap) is close to the average level of Western countries. This is a first approximation of the scales and patterns of restaurants food waste in Chinese cities, which can help inform the strategies on food waste reduction (Wang et al., 2017). In addition, the accuracy of waste composition analysis relies on the methods used, and it has identified various sources of error (Lebersorger and Schneider, 2011).

- Surveys, diaries, records, and observation are other ways of direct measuring and approximating FLW data, which consumes less time and costs more than weighing. However, due to some factors such as personal views, the way of raw data collection,

**Table 1.3** Advantages and disadvantages of different methods used for food losses and food waste quantification

| | Method | Symbol | Time | Cost | Accuracy | Objectivity | Reliability |
|---|---|---|---|---|---|---|---|
| Direct measurement | Weighing | W | ●●● | ●●● | ●●● | ●●● | ●●● |
| | Garbage collection | G | ●●● | ●●● | ●●● | ●●● | ●●● |
| | Surveys | S | ●● | ●● | ●● | ●● | ●● |
| | Diaries | D | ●●● | ●● | ●● | ●● | ●● |
| | Records | R | ● | ● | ●● | ●● | ●● |
| | Observation | O | ● | ● | ● | ● | ● |
| Indirect measurement | Modeling | M | ●● | ● | ● | ●● | ● |
| | Food balance | F | ● | ● | ●● | ●●● | ●● |
| | Use of proxy data | P | ● | ● | ●● | ●●● | ●● |
| | Use of literature data | L | ● | ● | ●● | ●●● | ● |

and subjectivity of observers, the accuracy of the data collected may be lower. Surveys that include questionnaires can be completed by email or by phone, or by face-to-face interviews and expert estimation. But biases may occur in FLW estimation because this method depends on the memory of people and they may provide answers that the society expects. For example, Naziri et al. (2014) conducted questionnaire surveys, focus group discussion, and key expert interviews on postharvest losses of cassava during July and October 2012 in four individual developing countries (Ghana, Nigeria, Thailand, and Vietnam) to investigate the amount of losses and explore mitigation strategies. Diaries can be a heavy task for participants, and cause gradual decline of participants' enthusiasm (Langley et al., 2010), as well as difficulties in recruitment and high dropout rates (Sharp et al., 2010). In addition, keeping diaries may have influences on changes in awareness and behavior, which will lead to uncertain accuracy of the diaries (Sharp et al., 2010). For example, to analyze the composition of food waste in the United Kingdom households, Langley et al. (2010) asked 13 households to keep a diary for 7 days, recording the information on the type, origin, and weight of food waste. Records often cost less and take little time to get FLW data. Observation is a relatively quick way to estimate FLW, but the accuracy and reliability are questioned.

- Because of low cost and high feasibility, secondary data is widely used to measure the amount of FLW. But there is higher uncertainty among these methods. For modeling, the choice of model parameters and the relationship between these factors and the quantity of FLW would largely affect the results. For food balance method, the accuracy is determined by the quality and comprehensiveness of the food balance sheet data. The most cost-effective and feasible way to obtain data is by using proxy data and literature data, however, their accuracy primarily relies on the quality and representativeness of the source data used. If the data are uncertain and inaccurate, the results would also not be reliable.

In reality, no direct or indirect methods can be satisfactory. Despite the advantages, direct measurement usually involves a limited number of participants in a certain community or city and a certain stage of the food supply chain, which could lead to an unavoidable problem of deficiency of representativeness, especially for the large countries like the United States and China. On the other hand, indirect measurement can provide an overview of the entire country and various stages. A combination of direct and indirect measurement could be a better choice to illustrate the FLW problem. For policy making and mitigation strategies, based on the statistical data at the national or regional level it could determine the severity of the problem. For the design of effective intervention steps, using first-hand data and exploring the driving and influencing factors could be a good approach.

The choice of method has a significant impact on the FLW quantification, which could result in data disparity in the literature examined. For example, it was reported that the food manufacturing industry in Italy produced about 5.7 million tonnes of FLW in 2006 (Monier et al., 2010), while another study based on modeling estimated about 1.9 million tonnes of FLW for this sector (Bräutigam et al., 2014). Such big difference exists between them because they used different data sources and assumptions. The former one included FLW and recycled or reused byproducts, whereas the latter one adopted the loss rate in the manufacturing sector and the method reported by FAO (Gustavsson et al., 2013).

### 1.3.3 Food losses and food waste in general

#### 1.3.3.1 Farm losses and waste

At the agriculture production stage, the FLW in low-income countries is generally higher than that in medium/high-income countries, because there is more advanced technology and infrastructure for harvesting in rich countries. For example, it is reported that FLW at this stage accounts for the largest portion (26%) of the total FLW in South Africa (Spescha and Reutimann, 2013) whereas it makes up 13% of the overall FLW across the food supply chain in Canada (Nahman and de Lange, 2013).

According to the existing data, there is little information on FLW of food commodities in the agricultural production and harvesting stage. For different food categories, on a per capita level, cereal loss is the largest with a median of roughly 16 kg/cap. For example, it is reported that about 5%−9% of cereal was lost at this stage in China, and a similar trend can be seen in Ghana (World Bank, 2011). Fruits and vegetables are the second largest wasted category at this stage with a value of 13 kg/cap. However, there is a significant difference of fruit and vegetable losses/waste between less developed and industrialized countries. For example, fruit and vegetable FLW made up about 20%−30% of the total production in China (Liu, 2014) while it accounted for only 6%−15% at this stage in Italy (Segrè et al., 2014). The reason for the big difference is that more advanced and newer technologies are used in developed countries. There is a small farm FLW of meat and fish, dairy products, and eggs at the production level (Fig. 1.8).

#### 1.3.3.2 Postharvest losses and waste

Postharvest FLW occurs during the postharvest handling and storage, manufacturing, distribution, and retailing stages, where distinctive characteristics can be seen

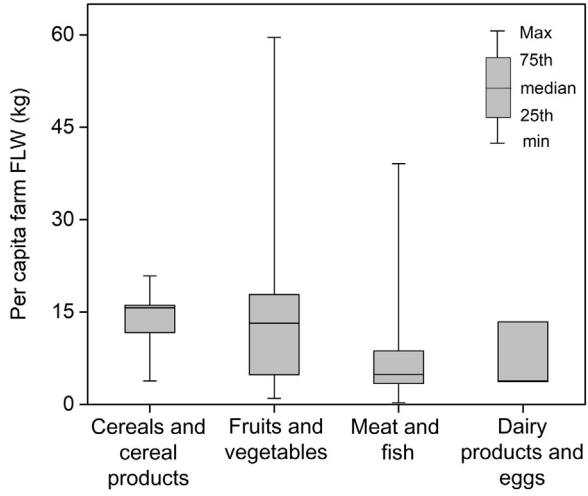


**Figure 1.8** Per capita farm food losses and food waste of different food commodities.

for different types of food. Fig. 1.9 shows postharvest FLW for different food commodities based on the existing data.

- As to cereals and cereal products, the postharvest FLW varies largely at different stages. Most FLW occurs at the postharvest handling and storage stage with a median value of over 18 kg/cap in developing countries. For instance, in South and Southeast Asia, cereals have the largest postharvest FLW in all food commodities. In particular, the postharvest FLW rate of rice, which is the staple food in Philippines, was 10% (FAO, 2014). Then the retailing stage is the second highest (over 10 kg/cap), followed by the manufacturing and distribution stages (5 kg/cap).
- Fruits and vegetables have the largest postharvest FLW among all the food groups on a per capita level. For example, the fruits and vegetables FLW at the manufacturing stage was more than 33 kg/cap in South Africa (Nahman and de Lange, 2013), which was far higher than that of all other food types or stages. It should be noted that there is less FLW at the manufacturing stage in developed countries, for example, it is only about 5 kg/cap in Denmark (Smil, 1981). The FLW at the distribution stage is approximately 17 kg/cap. The FLW at the retailing stage is small with a median value of 3 kg/cap.
- Meat and fish products have the least FLW during postharvest stages. There is little information for their postharvest handling and storage FLW. Based on the existing data, the FLW of meat and fish products at this stage is very small (about 0.3 kg/cap). FLW is similar for the manufacturing and retailing stages, both roughly with a median value of 1.3 kg/cap. For example, it is reported that the FLW rates of meat were 0.2%, 5%, and 0.5% for postharvest handling and storage, manufacturing, and distribution stages (Holm, 2013).
- There are also few studies for the quantification of postharvest FLW of dairy products and eggs. For the four substages, the median FLW is at approximately 6, 3, 0.2, and 3.4 kg/cap, respectively. Due to the poor cooling systems, the FLW of milk in the manufacturing and distribution stages was 3%−15% and 8%−11% in Ukraine, respectively (Holm, 2013).

It should be noted that the retailing FLW in the United States attracts a special attention in the literature. It is reported that roughly 2.4 million tonnes of food was lost at the retailing stage in 1995, but it rose to 19.5 million tonnes in 2010, accounting for 10% of the available food supply in the United States (WRAP, 2008). Fig. 1.10 shows that cereals and cereal products, vegetables, and fruits have the greatest contribution to the retailing FLW, with a median value of 10.5, 8, and 6 kg per capita, respectively. For example, some studies point out that the cereal products FLW at the retailing stage makes up 12% of the United States food supply (Buzby and Hyman, 2012). It is also estimated that the FLW of fresh fruits, vegetables, and meat and seafood in the supermarket were 11.4%, 9.7%, and 4.5% on average, respectively (Buzby et al., 2009) in 2005/2006, which is consistent with the estimates of the other developed countries. These data suggest that fresh products dominate in the retailing FLW because of factors like expired shelf dates, overstocking, product damage and quality problems, and inappropriate inventory rotation (Kantor et al., 1997). But FLW at the retailing stage in developed countries, including the United States, mostly takes place in the supermarkets rather than street markets and nonsupermarkets (often found in developing countries).

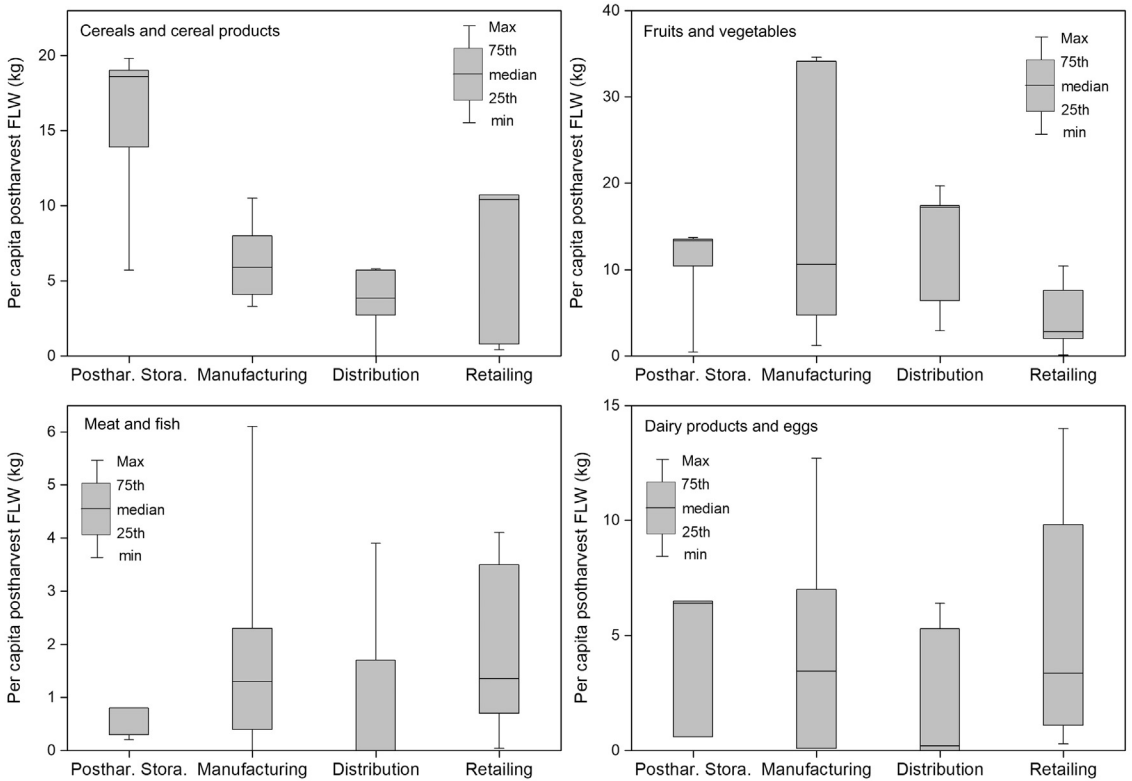


**Figure 1.9** Per capita postharvest food losses and food waste at different stages of cereals and cereal products, fruits and vegetables, meat and fish, and dairy products and eggs.

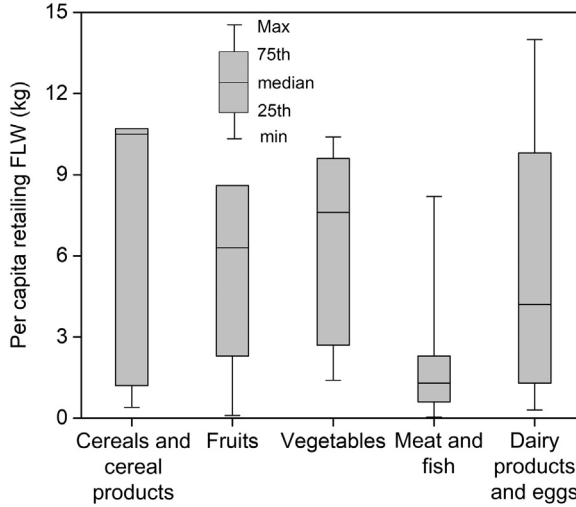


**Figure 1.10** Per capita food losses and food waste of different food commodities at retailing stage in the United States.

### 1.3.3.3 Consumer food waste

- *Household food waste*

Because of limited disposable household income, low-income countries normally waste little food in households. Food waste in households comprises the largest portion of the total FLW in medium/high-income countries, mainly due to poor purchase planning, excessive cooking, overstocking, or misunderstanding the "best before" and "use by" dates (Koivupuro et al., 2012). In the Europe Union, about 38 million tonnes or 42% of the total food was wasted in households, with an average of about 76 kg/cap (FUSIONS, 2015). In Canada, household food waste accounted for 51% of the total FLW along the food supply chain (Gooch et al., 2010). There was about 19% of food and drink bought into households in the United Kingdom, which also represented 70% of the total FLW at postharvest stages and consumption stage (WRAP, 2013). However, according to the existing studies, there is little first-hand data for households in emerging and developing countries. The FLW in households may be much larger than expected, especially in urban areas. Since there is lack of field research in these countries, generalization should be undertaken with caution.

Fig. 1.11 shows a positive relationship between per capita GDP and per capita household food waste. When per capita GDP goes up, the per capita food waste generation from households also sees the same trend. Some previous studies also indicate the same pattern (Holm, 2013). For example, it was estimated that in 2007, food waste produced in South African households was only 7.3 kg per capital (or 0.35 million tonnes in total) (Oelofse and Nahman, 2013) while households in the United Kingdom generated 109.3 kg/cap (or 6.7 million tonnes in total) (Lee et al., 2010).

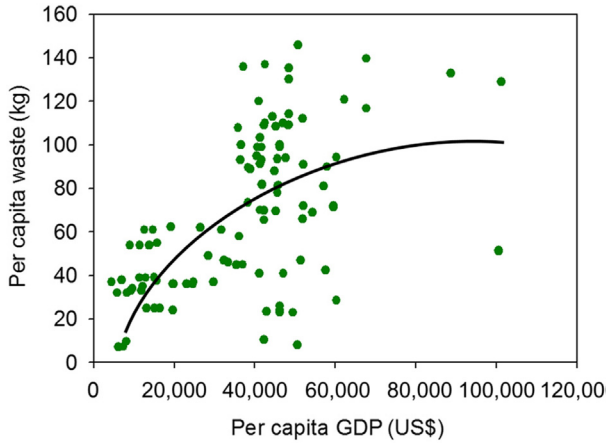


**Figure 1.11** Relationship between per capita gross data product and per capita household food waste.
Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

However, interestingly, when per capita GDP reaches above a certain level (about USD 50,000), the per capita food waste generation tends to be stable. This might relate to the growing awareness of the public, food waste prevention initiatives, and the impact of market mechanisms (e.g., increasing the price of food and disposal cost of food waste). For example, Australia (Thi et al., 2015) and the United Kingdom (Quested et al., 2011) have effectively taken some campaigns such as "Zero Waste" and "Love Food Hate Waste" against food waste. As a result, FLW from households has reduced by 21% between 2007 and 2012 in the United Kingdom. On the other hand, it may also involve more prepared food consumed and less cooking from scratch in rich countries, which may transfer food waste from household to food industry to some degree.

- *Out-of-home food waste*

Many researchers have studied the situation of food waste outside the home, that is, in the food service industry, including for example restaurants (Papargyropoulou et al., 2014), canteens (Halloran et al., 2014), schools (Okazaki et al., 2008), hospitals (Dias-Ferreira et al., 2015), care centers (Silvennoinen et al., 2015), military institutions (Davies and Konisky, 2000), and in-flight (Li et al., 2003), anywhere responsible for preparing or providing food away from home.

Most research on out-of-home FLW is carried out in the industrialized countries. For example, it was reported that 0.92 million tonnes of food was wasted in this sector every year in the United Kingdom (Parry et al., 2015). In Germany, this sector was the second largest source of food waste, accounting for 17% of the total FLW along the food supply chain (Kranert et al., 2012). In Finland, it was the third

largest contributor of FLW (20%) with 0.075−0.085 million tonnes of food wasted, following household (35%) and food industry (27%) (Silvennoinen et al., 2012).

It should be noted that China, as the largest emerging economy in the world, was also facing a high level of food waste in the catering industry, making up about 11%−17% of all food ordered (Liu, 2014). For example, it was reported the total quantity of Horeca (hotels, restaurants, and cafés) food waste in Lhasa (western China, with lower income compared with Western countries) has reached a high level of FLW. However, due to strict regulations issued recently (e.g., the public expense for official extravagance and governmental reception meals), on a per capita level, Horeca food waste generation in Lhasa has decreased from 128 to 98 g/cap/meal during 2011 and 2015 (Wang et al., 2018). Another pilot study focused on the situation of plate waste in school lunch programs in Beijing; it was reported that the average amount of food waste generated by students in Beijing was 130 g/cap/meal in 2014, making up 21% of the total food served. Food supply models, the quality of canteen service, eating habits, and students' knowledge of agricultural production were the main driving factors that influence plate waste (Liu et al., 2016).

In general, food waste per capita out-of-home is lower than that in households (Fig. 1.12). Assuming that as the per capita GDP and living standards increase, people would consume more food out-of-home, it may bring greater food waste for a variety of reasons, such as oversized dishes and taste. However, the relationship between per capita GDP and per capita food waste outside households seems not that significant. The reason can be explained by the fact that the food service sector

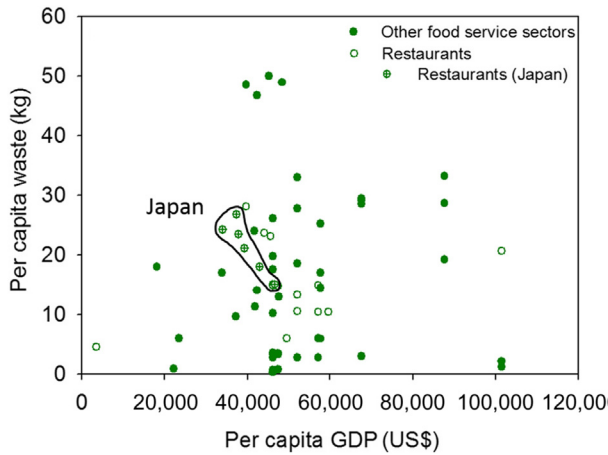


**Figure 1.12** Relationship between per capita gross data product and per capita out-of-home food waste. It differentiates restaurants (empty circles) and other food service sectors (e.g., canteens; filled circles), and the circles with a cross enclosed are for restaurants in Japan. Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

is diverse, including the "for profit" (e.g., restaurant) and "cost" (e.g., care center) parts, which results in a mixed pattern generation of food waste. It is interesting to point out that food waste in restaurants in Japan shows a downward trend in these years. This may partly relate to the implementation of the Food Recycling Law in Japan in May 2001, which set specific targets for industry sectors to reduce food waste generation. As a result, food waste out-of-home reduced from 3.1 million tonnes in 2007 to 1.92 million tonnes in 2012 (Parry et al., 2015).

### 1.3.3.4 *Comparison of food losses and food waste for different development levels of countries*

In Fig. 1.13, we take cereal as an example to show the evolution of food waste at different stages in the supply chain and economies with different development levels, using the United States, China, and South Africa as representative of industrialized, emerging, and average developing countries. Here we take food losses

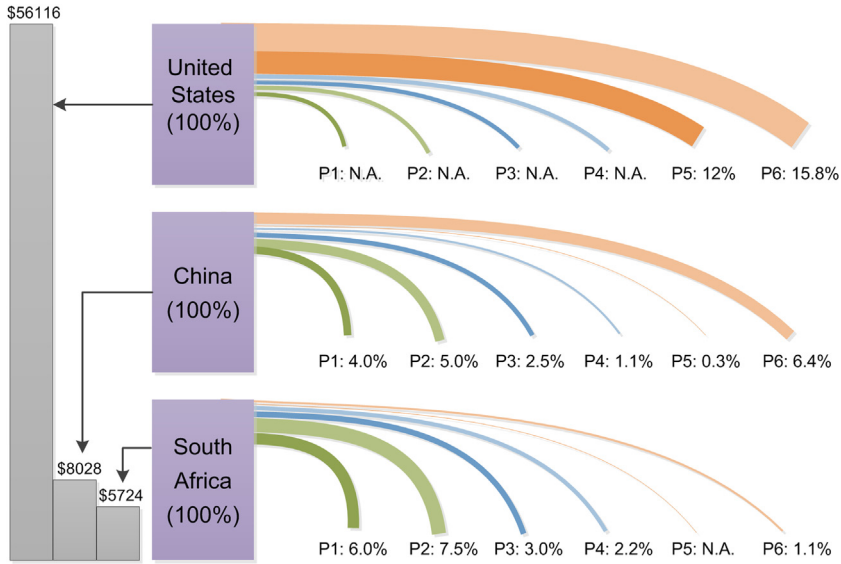


**Figure 1.13** FLWR of cereals throughout the food supply chain in the United States, China, and South Africa. The vertical chart on the left represents per capita gross data product in current USD in 2015 for these three countries (according to the World Bank).
P1 = agricultural production and harvesting, P2 = postharvest handling and storage, P3 = manufacturing, P4 = distribution, P5 = retailing, P6 = consumption. N.A. means not available. The reference flow is assumed to be a fictive output of 100% of the amount produced.
Source: Adopted from Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., et al., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51 (12), 6618−6633.

and food waste rate (FLWR) as an indicator to illustrate the situation, which represents the share of FLW to the total agriculture production.

- As a highly industrialized country, there is little information for cereal losses during postharvest stages in the United States. It could be assumed to be low. For South Africa, the FLWR at agricultural production, postharvest handling and storage, manufacturing, and distribution stages are all higher than those in China. This indicates that as awareness increases and the economy grows, China has adopted more advanced technologies and efficient storage systems in agricultural production, and has largely used improved transportation with large volumes (Liu et al., 2013). This also means it could be an efficient way to reduce FLW by improving the technologies and infrastructure in developing countries such as South Africa.
- With the development of the country and the increase of GDP, cereal waste at the consumption stage also increases. The FLWR of cereals at this stage in the United States is the highest (15.8%) among the three countries, which is around 2.5 and 14.4 times that in China and South Africa, respectively. In China, with the rapid development of economy and the improvement of living standards, the FLWR of cereals has increased to 6.4% in recent years, which is higher than that of all the other stages. For the average developing country, the FLWR of cereals at consumption stage is low in South Africa (1.1%). It should be pointed out that different countries have different production and consumption patterns of cereals, which may contribute to the differences among these countries.

## 1.4 Implications for future

The study suggests that FLW have attracted more attention, with more than 60% of FLW data reported in recent years. Although they provide an overview of the scale of FLW globally, for a few industrialized countries, and different food supply chain stages such as household, there are still data gaps and deficiencies as to the magnitude of FLW in developing countries (e.g., China and India) that have undergone rapid dietary transformation from starchy staples towards more diverse and fresh food (Parfitt, 2013).

In this case, we list some directions for future study as follows (Fig. 1.14):

First, the systems and methodologies for FLW quantification should be harmonized. It is important to consider these aspects: the definition of FLW [e.g., avoidable and unavoidable food waste (Östergren et al., 2013), food for human consumption vs nonhuman consumption], food supply chain stages (e.g., different segments at consumption), the classification and conversion factors of food commodities (e.g., procedure to convert cooked food items to different categories of raw food products), the treatment of FLW (e.g., donation, incineration, feed production, or landfill), the measurement units (e.g., physical weight, calories, or percentages), and the measurement methods. This would help to compare the available data among countries, food commodities, and stages in the food supply chain, which will further enable exploration of driving factors and patterns of FLW generation. For example, the recent released global Food Loss and Food Waste Protocol (World Resources Institute, 2016) in 2016 is an excellent first step, providing a

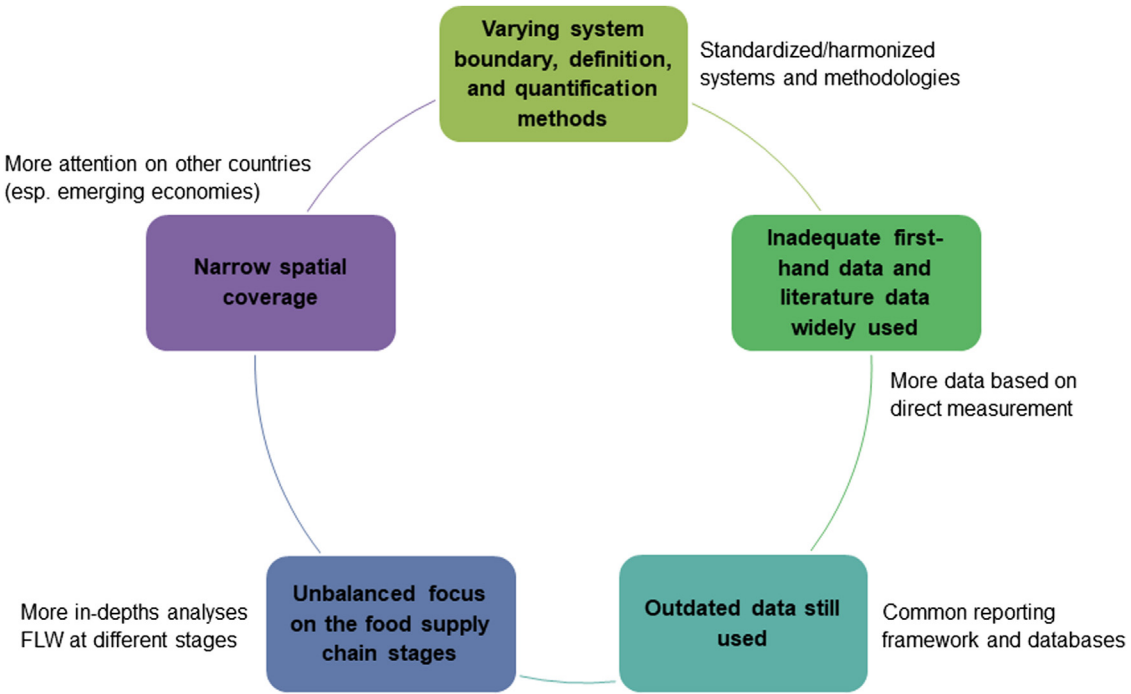


**Figure 1.14** Gaps and way forward of the existing global food losses and food waste database.

standard that can be used by any entity and should be promoted more largely. More efforts are needed to further refine and implement these kinds of harmonized methodologies.

Second, there is an urgent need for more data based on first-hand sources. The results show that only about 20% of the existing publications relied on first-hand data. Depending on the unrepresentative data from literature largely may result in high uncertainties. Although the time, labor, and economic cost are high, more field work and collection of first-hand data should be encouraged, which could help verify the existing data, improve the accuracy and reliability of the data, and fill in the gaps where data are not available.

Third, it should focus on the regions that are experiencing rapid development and emerging economies, such as the BRICs, that is, Brazil, Russia, India, China, and South Africa, other than the current hotspot areas (e.g., United States and Europe). There is less information on the quantification of FLW in those developing countries, but the situation may be serious; for example, a report shows that food waste at the consumer level in China is higher than that of the total in EU27 (Liu, 2014). Those countries are also undergoing rapid changes in diet structure, urbanization, and growing household income, which might bring a higher FLW in the future. Relying on the outdated data may result in overestimating FLW at agricultural production stage and underestimating food waste at consumption stage in developing countries (Liu, 2014; Shafiee-Jood and Cai, 2016). In addition, when more data are available for specific countries or cultures, it is better to consider social and cultural background in the FLW quantification and mitigation.

Fourth, deeper analyses should be conducted on FLW at different stages in the food supply chain. The results show that about half of the existing studies focused on the household food waste mainly in developed countries. More attention should be paid to the stages that have less data and are poorly understood, for example, FLW out-of-home (e.g., canteens and restaurants) and postharvest stages in less developed countries. It would help to identify the drivers of FLW at different stages with a more detailed quantification.

Fifth, research should build and maintain consistent databases under a common reporting framework on FLW, and then make the data available to the public through joint efforts from all stakeholders in the whole food supply chain. Those databases would contribute to track the progress towards achieving SDG Target 12.3 and national targets on FLW, as they would provide a benchmark for tracking the progress of FLW reduction. The governmental and nongovernmental organizations such as the UNEP and FAO, as well as national statistical agencies, should play a strong leadership in this area. For example, the data series reported by USDA-ERS and WRAP are good models. It should encourage all related industry or industry associations to report their FLW regularly. In the long term, it is applicable to track FLW reduction by using the "measurable, reportable, and verifiable (MRV)" principle.

Last but not least, quantifying FLW is the foundation for further analysis. Better data measurement would help better understanding of the social, economic, and environmental impacts of FLW, determine hotspots that should be given priority

actions, build long-term scenarios to inform the effective policy making and strategies in achieving reduction of FLW, and contribute to improve the efficiency and sustainability of the food system. It should carry out research focusing on these topics at the same time.

## 1.5 Conclusions

FLW has become a global concern in recent years and has also become a priority in the global and national political agenda. There has been a growing body of literature on FLW quantification in the past decade. However, there are still major gaps, such as various definitions of system boundaries and quantification methods, data deficiencies, narrow geography, and unbalanced food supply chain coverage. Most existing studies are carried out for a few developed countries (e.g., the United Kingdom and United States) and concentrate on the retailing and consumption stages (e.g., household), and more than half of them are based only on secondary data, which signals high uncertainties. The existing data indicates that at farm level, FLW in developing countries is higher than that in developed countries. Per capita fruit and vegetable FLW dominates at postharvest stages. With the increase of per capita GDP, per capita food waste from household also goes up. More standardized systems and methodology, more data based on direct measurement, more in-depth analysis of FLW at different stages, a common reporting framework, and more attention to the emerging economies, are urgently needed to properly inform relevant policy on the reduction of FLW and mitigation strategies on environmental impacts.

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