Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

What gets measured gets managed: A new method of measuring household food waste

Efrat Elimelech [a,b,*], Ofira Ayalon [a,b], Eyal Ert [c]

[a] Department of Natural Resources and Environmental Management, Faculty of Management, University of Haifa, Mt. Carmel, Haifa 3498838, Israel
[b] The Natural Resources and Environmental Research Center (NRERC), University of Haifa, Mt. Carmel, Haifa 3498838, Israel
[c] Department of Environmental Economics and Management and The Center for Agricultural Economic Research, Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot 76100, Israel

ARTICLE INFO

Article history:
Received 21 October 2017
Revised 12 February 2018
Accepted 16 March 2018
Available online xxxx

Keywords:
Food waste quantification
Food waste composition
Avoidable food waste
Food waste generation rate
Household food waste

ABSTRACT

The quantification of household food waste is an essential part of setting policies and waste reduction goals, but it is very difficult to estimate. Current methods include either direct measurements (physical waste surveys) or measurements based on self-reports (diaries, interviews, and questionnaires). The main limitation of the first method is that it cannot always trace the waste source, i.e., an individual household, whereas the second method lacks objectivity. This article presents a new measurement method that offers a solution to these challenges by measuring daily produced food waste at the household level. This method is based on four main principles: (1) capturing waste as it enters the stream, (2) collecting waste samples at the doorstep, (3) using the individual household as the sampling unit, and (4) collecting and sorting waste daily. We tested the feasibility of the new method with an empirical study of 192 households, measuring the actual amounts of food waste from households as well as its composition. Household food waste accounted for 45% of total waste (573 g/day per capita), of which 54% was identified as avoidable. Approximately two thirds of avoidable waste consisted of vegetables and fruit. These results are similar to previous findings from waste surveys, yet the new method showed a higher level of accuracy. The feasibility test suggests that the proposed method provides a practical tool for policy makers for setting policy based on reliable empirical data and monitoring the effectiveness of different policies over time.

1. Introduction

1.1. Cutting food waste to meet the UN's Sustainable Development Goals

The Sustainable Development Goals (SDG) comprise a collection of 17 goals set by the United Nations (UN) as a universal call to action to protect the planet and ensure that all people enjoy peace and prosperity. SDG-12 addresses the challenge of ensuring sustainable consumption and production patterns (UN, 2015). One of its focal points is unsustainable patterns of waste generation. Target 12.3 calls for reducing food loss, which refers to the decrease in edible food mass throughout the entire supply chain (Gustavsson et al., 2011), and cutting in half per capita global food waste, which refers to final consumption (Gustavsson et al., 2011), by 2030 (UN, 2015).

There are three main aspects to the growing concern over food loss and waste. The first of these concerns food security – the need to feed the growing population, which is predicted to reach 9.8 billion by 2050 (UN, 2017). The threat is so severe that studies suggest the world will need 70% to 100% more food by 2050 (e.g., Gomiero et al., 2011). Cutting food loss and waste is a possible solution for ensuring food security (e.g., Foley et al., 2011; Godfray et al., 2010; Kummu et al., 2012; Smith and Gregory, 2013). The second aspect concerns monetary losses. Annual losses due to food loss and waste are estimated at $1.3 billion in the US alone (Buzby et al., 2014), while around the globe they amount

Abbreviations: CBS, Central Bureau of Statistics; FAO, Food and Agriculture Organization; $GtCO_2$ eq, gigatons of CO_2 equivalent; ID, identification code; IQR, interquartile range; MSW, municipal solid waste; NIS, New Israeli Shekel; QR code, quick response code; RFID, radio frequency identification; SDG, Sustainable Development Goals; SII, Standards Institution of Israel; SWA - Tool, Methodology for the Analysis of Solid Waste; UN, United Nations; US, United States; WRAP, Waste & Resources Action Program.

* Corresponding author at: Department of Natural Resources and Environmental Management, Faculty of Management, University of Haifa, Mt. Carmel, Haifa 3498838, Israel.

E-mail addresses: eelimelec@staff.haifa.ac.il (E. Elimelech), ofira@sni.technion.ac.il (O. Ayalon), eyal.ert@mail.huji.ac.il (E. Ert).

https://doi.org/10.1016/j.wasman.2018.03.031
0956-053X/

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

to $750 billion (FAO, 2013). Financial losses per household reach $566–$593 a year in Italy and the United Kingdom, respectively (Secondi et al., 2015). The third aspect concerns negative externalities – the carbon footprint of global food loss and waste equals 3.6 $GtCO_2$ eq (FAO, 2016). Other negative externalities resulting from food loss and waste include air and water pollution, soil erosion, salinization, and nutrient depletion.

According to the Food and Agriculture Organization (FAO), one-third of global food production is lost every year. However, there is no consensus on that proportion, and estimates actually range between 10% and 50% of total global food production (Parfitt et al., 2010). As these discrepancies might suggest, although research on food loss and waste has significantly increased with time (Chen et al., 2017, Xue et al., 2017), major data and methodology gaps remain unresolved. Data regarding the amount of food waste is fragmented and inconsistent (Bellemare et al., 2017; Hoj, 2012; Roodhuyzen et al., 2017), and different studies have employed different definitions and methods (Chaboud and Daviron, 2017; Garcia-Garcia et al., 2017; Hebrok and Boks, 2017; Janssen et al., 2017; Parfitt et al., 2010; Ponis et al., 2017; Ramukhwatho et al., 2017; Richter and Bokelmann, 2017). Therefore, researchers have stressed the need for commonly agreed-upon and improved metrics for food waste (e.g., Stenmarck et al., 2016; Williams et al., 2015).

The current article presents a new measurement method to quantify household food waste designed to address the shortcomings of current measurement methods. This new method focuses on individual households and on collecting and measuring each household's waste on a daily basis. The identification of individual households' waste connects food waste with its source, even when multi-family buildings are studied. The feasibility of establishing this connection suggests some new, exciting research opportunities, such as investigating the relationship between self-reports and physical waste measures. Questions of interest may include how actual food waste relates to household routines, beliefs, and/or attitudes, and how accurate self-report estimates are in predicting actual waste. The second feature, which is the collection of waste on a daily basis, implies that waste is still fresh when measured. Waste freshness is important, as it increases the accuracy of the measurement and makes the differentiation and categorization of food items less difficult.

This article begins with a brief discussion of current measurement methods, as well as their main advantages and disadvantages (Sections 1.2–1.4). It continues with the presentation of the new method and explains how its design may address current challenges in sampling food waste (Section 2). This presentation is followed by a "proof of concept" study designed to test the feasibility of the proposed new method (Section 3). The article concludes with a discussion of the main characteristics of the new methodology and its potential usefulness for scholars and practitioners in the field (Sections 4 and 5).

Our focus on households is motivated by recent evidence that suggests that most of the food loss and waste in the developed world result from household consumption habits (Gustavsson et al., 2011; Jorissen et al., 2015; Lipinski et al., 2013; Monier et al., 2010; Parfitt et al., 2010; Parry et al., 2015; Rutten et al., 2013; Stenmarck et al., 2016). Demographic factors, psychographic factors, and socioeconomic characteristics have all been proved to be related to household food waste discarding behavior (Aschemann-Witzel et al., 2015; Secondi et al., 2015). Apparently, per capita food waste in the household tends to increase with an increase in per capita GDP (Xue et al., 2017).

The serious consequences of food loss and food waste, along with the difficulties in measuring it, imply a significant challenge for scholars and practitioners alike. The proposed "Daily Family Waste Collection" method aims to address at least some of the difficulties involved in the current mainstream methods of measuring food waste. In the next section, we briefly describe the current measurement methods to clarify the existing challenges. This short report is by no means an extensive review of the literature, but rather a brief description of notable benchmarks aimed at clarifying the properties of existing methods.

1.2. Food waste measurement methods

Assessments of food waste generation along the supply chain are fraught with considerable uncertainties (Bräutigam et al., 2014). Differences in definition systems and classification methods make it difficult, if not impossible, to compare food waste studies. Thus, establishing a valid estimation of the extent of food waste remains major challenge (Bräutigam et al., 2014; Girotto et al., 2015; Parfitt et al., 2010; Stenmarck et al., 2016; Williams et al., 2015).

Current food waste measurement can be classified into three major types. The first takes a top-down approach, in which data is based on mass balance or extrapolation of existing waste databases (e.g., Beretta et al., 2013; Bradley et al., 2009; Bräutigam et al., 2014; Herzog et al., 2016; Herzog et al., 2017; Kotzer et al., 2015; Priefer et al., 2013). The main strength of this method is the access to large amounts of data, which could facilitate comparability, although when combining different databases, this advantage might be diminished (Moller et al., 2014).

The second type of food waste measurement focuses on self-reporting methods, including questionnaires (e.g., Jorissen et al., 2015; Lorenz et al., 2017; Pekcan et al., 2006; Ponis et al., 2017; Quested and Luzecka, 2014; Stefan et al., 2013), food waste diaries (e.g., Koivupuro et al., 2012; Langley et al., 2010; Quested et al., 2013b; Richter and Bokelmann, 2017; Williams et al., 2012), and interviews (e.g., Aschemann-Witzel et al., 2015; Glanz, 2008; Parfitt et al., 2010; Ramukhwatho et al., 2017). Using questionnaires requires a good sample design and large sample sizes (Moller et al., 2014; Zorpas and Lasaridi, 2013). The strength of this method is that it is less invasive, time consuming, and expensive than direct measurements (Hoj, 2012; Visschers et al., 2016). However, it is implicitly based on the assumption that respondents can accurately recall specific waste events and accurately assess the amount of food wasted (Hoj, 2012). The fact that, in reality, respondents might not really know the exact amounts of waste they produce may undermine the reliability of this method (Visschers et al., 2016; Xue et al., 2017).

Interviews are considered a good tool for providing close observations of food waste practices and amounts (Moller et al., 2014), yet they are prone to biases similar to those of self-reporting. Interviews also dictate small sample sizes that might compromise representativeness (Moller et al., 2014; Zorpas and Lasaridi, 2013).

It is widely agreed that in order to accurately measure food waste weight and composition, one must record them as closely as possible to the point at which the food enters the waste stream (European Commission, 2004; Langley et al., 2010). Food waste diaries, in which waste is recorded each time it is produced, put this notion into practice. However, food diaries are also subject to self-reporting biases (e.g. Moller et al., 2014; Xue et al., 2017). The "observer effect" (Langley et al., 2010), for example, is a form of social desirability bias whereby people change their waste-discarding habits or underreport their waste in order to present themselves in a positive light in accordance with the well-known social desirability and experimenter demand effects (Hebrok and Boks, 2017; Hoj, 2012; Langen et al., 2015; Langley et al., 2010; Moller et al., 2014; Neff et al., 2015; Porpino, 2016). Another challenge of working with food waste diaries is that they are time-consuming and costly, and thus are mainly suitable for short sampling periods and small sample sizes (Moller et al., 2014; Xue et al., 2017; Zorpas and Lasaridi, 2013).

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

In summary, the main strength of self-reporting methods is their ability to provide firsthand insights into food discarding habits (Moller et al., 2014; Richter and Bokelmann, 2017). When questionnaires are employed, large samples may be used at relatively low cost. The main disadvantage of self-reports is their inaccuracy in measuring waste levels that tend to be understated, e.g., due to social desirability, causing respondents' conservation efforts and environmental awareness to be exaggerated. Interviews and waste diaries are also costly and only suitable for small samples.

The third type of waste measurement involves direct measurements, also known as physical waste surveys (e.g. Edjabou et al., 2016; Fehr and Romao, 2001; Gutiérrez-Barba and Ortega-Rubio, 2013; Hanssen et al., 2016; Lebersorger and Schneider, 2011; Parizeau et al., 2015; Quested et al., 2013b; Schott and Andersson, 2015; Schott et al., 2013; Waste Not Consulting, 2015), which are the focus of the current article. Section 1.3 presents an in-depth discussion of this method.

1.3. Physical household waste surveys

In a physical waste survey, different waste fractions and components are classified into different categories, such as edible/inedible fractions, and weighed (Moller et al., 2014). This method is considered more objective and accurate than self-reporting methods, as it is carried out by a third party (usually a subcontractor of the local authority) who has expertise in field waste surveys (Jorissen et al., 2015; Langley et al., 2010; Lebersorger and Schneider, 2011).

Measurement of municipal solid waste (MSW) composition is a well-known and standardized practice (e.g., ASTM International, 2016; European Commission, 2004; Nordtest, 1995; SII, 1996; Toivonen and Sahimaa, 2014, among others), yet, no standardized guidelines have been developed for conducting physical surveys of food waste (Jorissen et al., 2015; Langley et al., 2010; Lebersorger and Schneider, 2011). Compared to MSW surveys, food waste analyses require higher sorting and classification resolution, for example the identification of individual food items, such as different types of fruit and vegetables or dairy products, food leftovers, and so on. Applying physical waste survey methods to food waste quantification requires some adjustments due to the level of identification and classification employed, though accumulated knowledge from measuring MSW can certainly constitute an advantage. The following sections outline some major challenges in measuring household food waste using physical waste surveys. These challenges refer to the practice of sampling and sorting MSW in general and food waste in particular.

1.4. Challenges in measuring household food waste using physical waste surveys

1.4.1. Sampling shared waste bins

In sampling single-family houses, each waste bin can be distinctly associated with a particular household (Hanssen et al., 2016; Quested et al., 2013a). The challenge arises in sampling multi-apartment buildings or mixed-use development areas (commercial and residential, for example), where shared waste bins are in place and it is not clear which household uses which waste bin, or whether the bin also serves a local business or a public utility (Dahlén and Lagerkvist, 2008). This lack of clarity could influence variation in results. It also undermines the ability to differentiate between sectors and (Dahlén and Lagerkvist, 2008; Sahimaa et al., 2015) link waste bags and their production source. Current practices include: (1) Extracting subsamples from shared waste bins. For example, when sampling a 1100-liter waste bin, only a subsample of 240-liter is analyzed (European Commission, 2004; Lebersorger and Schneider, 2011; Seagull Environmental Planning Ltd., 2014); (2) Sorting samples collected from multi-apartment buildings in "batches" (e.g., Edjabou et al., 2016). Both of these practices, however, exclude the option of drawing conclusions at the household level.

1.4.2. The 'age' of the waste sample

The age of the sample is influenced by the time gap between the waste's disposal and its sampling and sorting. The sample includes all the waste accumulated in the bin at the time of sampling, so the actual age of the waste samples is uncertain and may vary from a few minutes to a few days. This uncertainty restricts the identification, separation, and classification of each waste item (Langley et al., 2010).

In order to avoid compromising the sample's physical and chemical properties, for example through waste compaction, wetting of the waste's dry components, dehydration of the wet residuals, and biochemical processes that change the waste's composition, Dahlén and Lagerkvist (2008) recommend that each sample be sorted within two days from the sampling day, preferably on the same day. Lebersorger and Schneider (2011) argue that a violation of the two-day time limit seems tolerable, considering logistical considerations such as collection intervals, the size of the sorting team, and the like. Both Hanssen et al. (2016) and Edjabou et al. (2016) reported on sorting samples within a week of the sampling day. It should be noted that a week's interval might raise severe barriers to the sorting process and the accuracy of the identification and separation of the waste components, especially in hot weather countries.

1.4.3. Degradability of organic matter

Degradation varies with the season and climatic conditions, and very much depends on collection intervals, which could be as long as 14 days, according to Langley et al. (2010), or 42 days, according to Lebersorger and Schneider (2011). Hanssen et al. (2016) argue that cold weather conditions eliminate evaporation. Edjabou et al. (2016) claim that food waste degradation is significantly minimized when the waste is sorted within a week of the sampling day. However, due to natural degradation, some waste items may ultimately be inseparable (Jorissen et al., 2015; Langley et al., 2010).

1.4.4. Waste compaction

Physical waste surveys are generally based on samples taken from ordinary waste-collection vehicles or waste bins (Dahlén and Lagerkvist, 2008; European Commission, 2004). Collection vehicles mix and compact MSW, thus decreasing its particle size and contaminating individual waste components (Dahlén and Lagerkvist, 2008; European Commission, 2004; Lebersorger and Schneider, 2011). A certain degree of compaction exists at the waste bin level as well, as a result of gravity and long collection intervals. Hence, identification of different waste fractions is challenging (Lebersorger and Schneider, 2011). Sahimaa et al. (2015) suggest that the smearing and sticking of materials can be managed more easily when each waste bin is sampled separately.

1.4.5. Unknown side flows of waste materials

Sampling waste from either waste bins or collection vehicles cannot ensure that all waste streams have been captured. Due to the use of yard composters or garbage disposal units, or even the ownership of a pet, some waste materials do not get to the waste bin and thus are not documented (Dahlén and Lagerkvist, 2008; Jorissen et al., 2015; Quested et al., 2013a). According to WRAP (Waste & Resources Action Program), approximately one fifth of all household food waste is disposed of via the sewer, with drinks and dairy products making up more than half of this (Gray, 2009; Quested et al., 2013b). Even with optimal synchronization between waste sample-taking and collection routes, it is not unreasonable to assume that some waste materials will be lost when discarded after sample collection or due to the use of other disposal routes (e.g., the kitchen sink, home composting, or pet food).

2. A new method of quantifying household food waste

The shortcomings of current physical waste surveys (as outlined in Section 1.4) suggest the need for improved measurement methods. The method we propose here is based on the principle of measuring waste of individual households on a daily basis. It includes the following four elements: (i) capturing food waste at the point at which it enters the waste stream; (ii) collecting waste samples at the doorstep (iii) using the individual household as a sampling unit; (iv) collecting and sorting waste daily. The next section describes this method and its advantages. Table 1 presents the ways in which these advantages may address the current challenges and their implications.

2.1. Doorstep sample collection

Waste samples, in coded garbage bags, are collected from the resident's doorstep. This practice provides maximum proximity to the waste-production source and guarantees that the waste is as close as possible to its original state. It also eliminates the need to coordinate between waste sampling and collection routes, and decreases the probability of waste side flows, as discussed below in Section 2.5. It also involves the processing of smaller samples while improving the relative accuracy of the results.

2.2. A single household serves as a sampling unit

Taking each household as a sampling unit draws a direct link between the waste-production source and the waste sample. It also makes it possible to both assemble a diverse sample consisting of single and multi-apartment buildings in rural or urban areas and sample households located in mixed-use development areas (commercial and residential). Researchers can document the amounts of food waste and MSW produced on a household level. Furthermore, the identification of households allows further investigation of households' waste-disposal behaviors, attitudes, and habits, e.g., by employing complementary questionnaires (Elimelech et al., unpublished results).

2.3. Sample collection on a daily basis

Waste samples are collected using a trailer (without compaction) on a daily basis for one week. This practice ensures "fresh" samples that preserve their original composition and density, with minimal mixing between different waste streams, simplifying identification and the sorting process. The practice of daily sample collection has been rejected by some scholars on the grounds of cost and inconvenience (Jorissen et al., 2015; Langley et al., 2010). Nonetheless, it has the potential to increase the relative accuracy of the sample, which can subsequently reduce the waste sample size, thus contributing to technical feasibility. From the participants' point of view, daily doorsteps waste collection can actually be regarded as a waste-disposal service.

2.4. Sample sorting on a daily basis

Sorting takes place within a few hours of collection. This practice obviates the need to store samples. It also eliminates the time interval between waste discarding, sampling, and sorting. As such, it resolves uncertainties that restrict the waste items' identification, and avoids inaccuracies regarding the sample's physical and chemical properties, as discussed in Section 1.4.2.

2.5. Capturing all waste streams

Collecting all waste streams produced in a household on a daily basis reduces the possibility of side flows of waste materials, with the exception of liquid food waste, which is for the most part discarded into the drainage or food leftovers that serve as pet food. Since all waste streams are collected, this method can be applied to any given municipal waste-collection scheme (i.e., mixed and/or source-separated collection schemes). Another advantage of collecting all waste streams is the ability to calculate the average amount of MSW produced on the household level, for example, by dividing the total amount of waste produced by a single household during the course of the study by the number of sampling days (e.g., kg of waste per household per day). This practice also creates a distraction from the true nature of the research, i.e., participants are unaware of the fact that the study is focused on their own food waste discarding behavior rather than on municipal waste measurements. This can help in reducing self-awareness and thus make subjects less likely to change their waste-discarding habits (Langley et al., 2010).

To the best of our knowledge, the idea of capturing food waste at the point at which it enters the waste stream has never been

Table 1
The main challenges in estimating food waste, and the solutions suggested by the new method.

Challenges in sampling food waste	Implications	Proposed solution in the new method
Proximity to the waste-production source	Decreased accuracy	Sampling waste from the household's doorstep
Long time gaps between waste discarding, sample collection, and sample sorting	Reduces the ability to identify, separate, and classify each waste item	Eliminating time gaps by collecting, sampling, and sorting waste on the day of disposal
Degradability of organic matter	Reduces the ability to identify, separate, and classify each waste item	Samples are collected on a daily basis, ensuring "fresh" samples that preserve the original composition and density
Unknown side flows of waste materials	Inaccurate description of waste composition and quantity	- Doorstep sample collection decreases the probability of waste side flows - All waste streams are collected
Sampling of shared waste bins	- Difficult to determine the exact number of households using a certain waste bin - Increased variation in waste composition	Each household represents a sampling unit, so there is a clear linkage between the waste-production source and its sample
Almost impossible to collect data on waste-discarding behaviors and practices that affect waste production	Difficult to evaluate the relationship between household behavior and waste production	Sampling waste at the household level grants access to valuable data regarding waste behaviors, attitudes, and habits

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

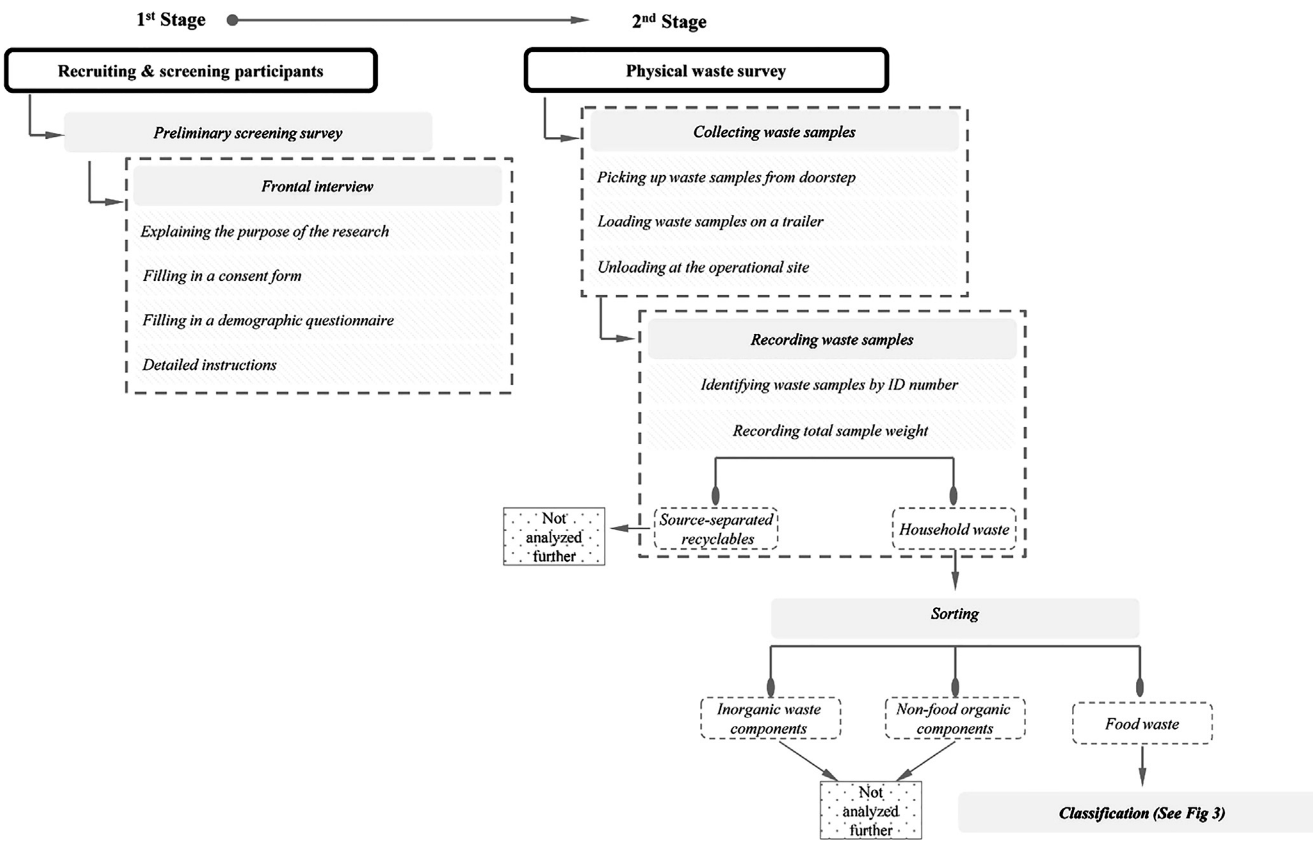

Fig. 1. A detailed flowchart of the "Daily Family Waste Collection" method.

tested in physical waste surveys. The suggested "Daily Family Waste Collection" method (Fig. 1) adopts an innovative approach whereby each household serves as a sampling unit and the samples are collected from each household's doorstep on a daily basis. In the next section, we report on a field study that we conducted in order to estimate the feasibility of the proposed method.

3. Implementation of the "Daily Family Waste Collection method: empirical evidence from a field study

3.1. Research area

The field study was conducted in eastern Haifa, Israel (Fig. 2), in three neighborhoods: Neve Sha'anan, Ramat Remez, and Yizraelia, with 36,730 inhabitants overall (Haifa Municipality, 2016). The population of this region is heterogeneous and consists of young and old families, immigrants, and students. The neighborhood includes mainly multi-apartment buildings, with typically two to four floors, and few high-rises. According to the socioeconomic index compiled by the Israeli Central Bureau of Statistics, the area is ranked in the sixth to seventh socioeconomic cluster (CBS, 2008) on a scale of 1–10 (with 1 representing the lowest socioeconomic cluster), which is typically referred to as the Israeli middle class (CBS, 2012).

Generally, a curbside scheme of mixed MSW operates in these three neighborhoods, alongside central collection of paper and plastic bottles. The Ramat Remez neighborhood also has a separate collection scheme for packaging waste. This arrangement implies that some households practice some sort of source separation of recyclables. Since a separate collection scheme for organic waste was not in place, it was assumed and further verified in the screening phase (Section 3.4), that most of that waste was indeed placed in the common mixed-waste bin.

3.2. The number of sampling units

The number of sampling units was determined according to the Methodology for the Analysis of Solid Waste (SWA-Tool, European Commission, 2004), with budgetary and logistical constraints. According to the SWA-Tool, the optimal number of sampling units needed in order to achieve 10% maximum random sampling error and 95% confidence level, given that the variation coefficient for household food waste is approximately 70% (data processed from the Israeli national waste composition survey – Seagull Environmental Planning Ltd., 2014), is 188 sampling units (households). The actual number of households in our study was 192.

3.3. Recruitment of participants

In order to recruit households, we hung recruitment ads on message boards throughout the neighborhoods, distributed leaflets in mailboxes, and posted on the municipal Facebook page and other informal community Facebook pages. The ad consisted of a call to participate in an innovative week-long study during which the research team would pick up the participants' waste bags from the doorsteps of their homes. Recruitment was an ongoing process that lasted five months and was performed in five separate rounds (March–August 2016). Interested participants were asked to email the researchers or scan a QR (Quick Response) code and fill in a short contact form. At the end of the study, each household received NIS 200 (~$57) in coupons as compensation for their participation.

3.4. Participant screening

The participants who responded to the ads (n = 297) were contacted by phone and asked to answer a short screening questionnaire. The purpose of this questionnaire was to determine

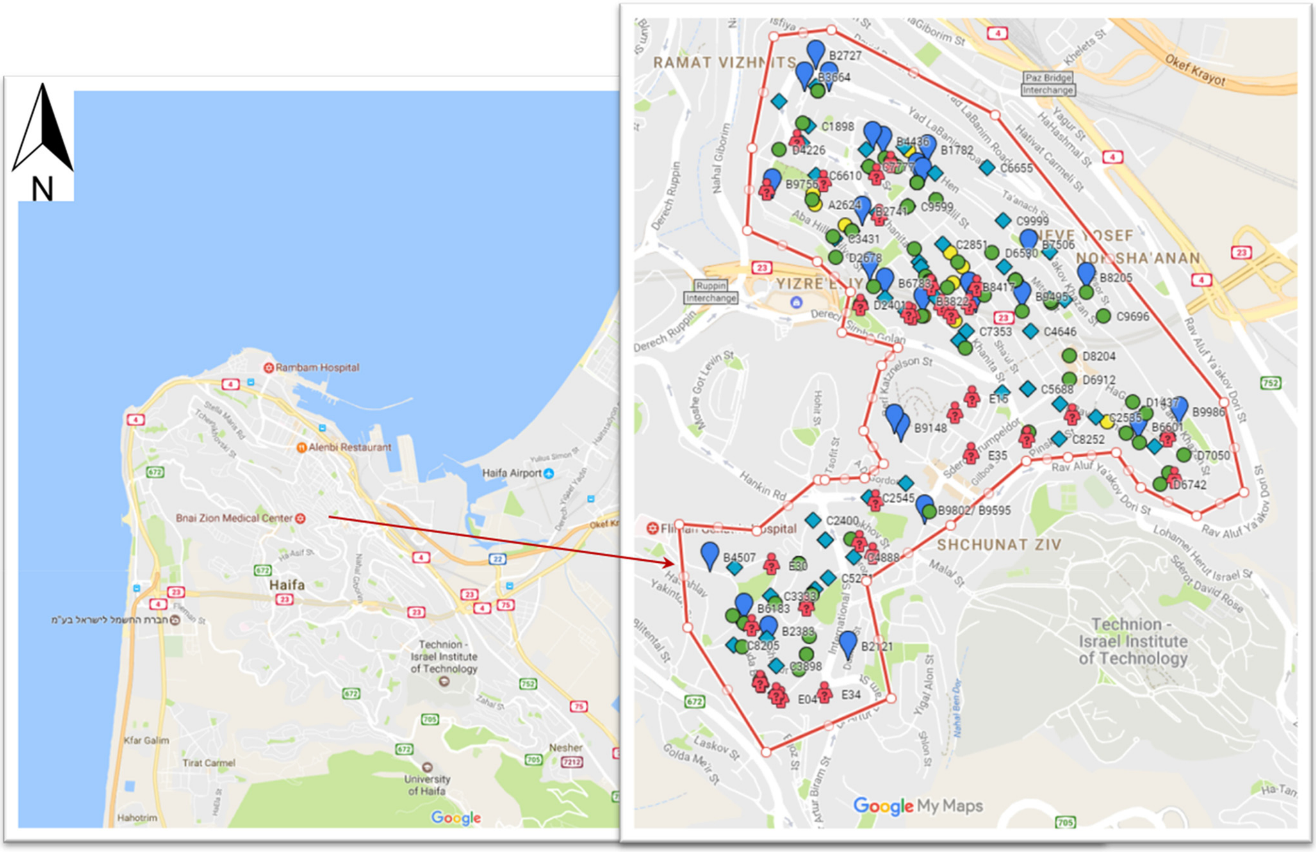

Fig. 2. Research area. Made with Google Maps. Each icon on the map represents a household. Different icons represent different rounds of research.

Icon	Research Round	No. of households
	A	14
	B	27
	C	54
	D	64
	E	34

whether the participants fit the selection criteria: living in the relevant geographical area, sharing a household with family members or a spouse (single individuals and roommates were excluded), and considering themselves secular or moderately religious (Orthodox households were excluded because of their unique characteristics, which might affect waste-generation patterns, in particular their distinctive lifestyle and large number of children).

Of the 297 potential participants, 18% did not meet the criteria, 9% were not interested in participating, and 3% were not available during the study period. Frontal interviews were scheduled with the 207 potential participants who met the criteria.

The frontal interviews were carried out by a team of four workers and usually conducted two weeks before the beginning of each research round. The interview consisted of three stages. First, potential participants were given a brief explanation regarding the purpose of the research. To minimize the risk of affecting households' waste-discarding routines (e.g., the above-mentioned "observer effect" described by Langley et al., 2010), participants were not exposed to the real purpose of the research. Instead, they were told that the study will be used by Haifa Municipality to optimize the city's waste-collection service. If further information was requested, interviewers were instructed to explain that learning about MSW composition would facilitate better planning of curbside recycling schemes (we used distracting examples such as "cardboard packaging," "plastic waste," and so on). Next, participants were asked to fill in a consent form and then take a short survey that included some demographic questions as well as questions about their waste disposal routines. A further survey, distributed at the end of the field survey, was designed to assess the relationship between household shopping routines, food preparation and food waste production, and between their estimates and their actual waste. Both subjects are beyond the scope of the current article and their results are reported elsewhere (Elimelech et al., unpublished results). Interviewers noted any access-related features (such as building entrance code, special identification marks on the door, lobby entrance, and so on) to ensure smooth collection of the waste bags. Each household was given a set of 20 garbage bags in their preferred size, a set of identification code stickers to mark their bags, printed instructions, and a cardboard box in which they were instructed to place their garbage bags.

In the final stage, detailed instructions regarding the course of the study were given to the participants, as follows:

(1) Maintain your regular waste discarding routines. If your household is not used to separate waste, hand over a mixed garbage bag, and if a separation routine is in place, maintain it, and hand over the separated streams in the coded bags.

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

(2) Special instructions: If you discard cooked meals, wrap them in a small garbage bag. If you discard diapers or animal feces, wrap them in a small garbage bag. If you discard packaged food, do not to separate the packaging from the food.
(3) Place your coded garbage bags on your doorstep every morning before 8:00 am during the week of the study.
(4) Under no circumstances should you throw your garbage bags into the garbage bin.

At the end of the screening process, 192 households (634 individuals) met the criteria and agreed to participate in the study (thirteen were not interested in participating and two were excluded because they failed to follow the instructions). Table 2 presents the descriptive statistics of the respondents.

The field study was conducted between March and August 2016. However, possible seasonal effects were controlled since samples were collected from participants' doorsteps, with minimum exposure to weather conditions. Nonetheless, since different seasons are characterized by different fruit consumption, seasonality might have had some effect on the composition of the vegetables and fruit category.

The study was carried out in five consecutive rounds, with each round consisting of a different number of households (from 13 to 64) (Fig. 2). The first round was a pilot in which logistical and timing aspects were tested. The size and timing of the following rounds were designed to avoid pre-holiday and post-holiday effects of national holidays and maintain the pace of recruitment.

3.5. Waste sampling procedure

Waste samples were collected from the household's doorstep on a daily basis over seven consecutive days (one week is the minimum sampling duration, as recommended by the SWA – Tool, ASTM D5231-92 and IS 2221). Collection lasted between three and five hours, depending on the number of households participating in each round and their distance from one another. Each sample collection was documented in the Google Forms app.

Table 2
Descriptive statistics of the respondents.

Sample size (households)	192
Sample size (individuals)	634
Average number of persons in household [SD]	3.3 [1.3]
Median number of persons in household	3.00
Gender of respondents, female (%)	75%
Education level of respondents (%):	
Secondary school	8%
Vocational training	11%
Academic degree	81%
Religiosity level of respondents (%):	
Secular	67%
Traditional	14%
Religious	19%
Average age of respondents (years) [SD]	37 [11.6]
Median age of respondents (years)	33
Age range of respondents (%):	
21–29	33%
30–39	34%
40–49	16%
50+	17%
Households with children (0–18 years, %)	60%
Median income range* (NIS) [US$**]	9000–115,000 [2630–3360]
Socioeconomic index	6–7 (out of 10)

* Eighteen respondents (9.37%) refused to report income information.
** Conversion rate of 3.427 NIS per 1 US Dollar.

3.6. Sorting procedure

Waste samples were unloaded at a sorting tent located at an operational site of the Sanitation Department of Haifa Municipality. Each waste sample was sorted separately (as practiced by Hanssen et al. (2016)). Waste samples that were collected on weekends (Saturday night) were stored in the work area and sorted the following morning. Sorting was carried out by a team of five workers, including a supervisor, and lasted five to six hours. Each waste bag was identified using its assigned identification code (ID) and documented on a form.

3.7. Classification procedure

Garbage bags that carried the same ID code were weighed together, with the exception of garbage bags that contained source-separated streams (usually paper and plastic bottles), which were weighed separately to record recycling rates. Next, the bag was opened, and the sorting and classification process began. All inorganic waste components were put aside and weighed together. Then nonfood organic components, such as houseplants and animal feces, were weighed. **Food waste**, the targeted fraction in this research, was classified as any raw (e.g., apples) or cooked food (e.g., cooked rice) (Monier et al., 2010).

Food waste classification was based on a unified protocol developed for this study, which contained detailed instructions for the sorting team in order to minimize subjective judgments. Food waste was classified into the following classes (Fig. 3):

I. **Unavoidable Food Waste** – waste arising from food preparation or consumption that is not now and never was suitable for human consumption (e.g., bones, eggshells, tea bags, fruit pits, apple cores). All "unavoidable food waste" in the sample was grouped together and weighed as one unit, with no additional classification process.

The definitions of unavoidable and avoidable food waste depend to some extent on both cultural and individual food consumption habits (e.g., Beretta et al., 2013; Edjabou et al., 2016; Lebersorger and Schneider, 2011; Ostergren et al., 2014; Quested et al., 2013b). Therefore, bread crusts, apple peels, mushrooms stalks, herb stems, and the like were classified as unavoidable food waste, typical to Israeli food consumption habits.

In an attempt to avoid any subjective judgment, we did not employ a third category of "possible avoidable food waste" (e.g., as suggested by Beretta et al., 2013; Monier et al., 2010, Quested et al., 2013a; and Ventour, 2008), and any food that some people eat and others do not, e.g., potato peels, was classified as unavoidable food waste. A similar distinction was applied by Lebersorger and Schneider (2011).

II. **Avoidable Food Waste** – food that is suitable for human consumption. Each food item was classified first into one of seven food categories (following national Household Expenditure Survey of the Israeli Central Bureau of Statistics (CBS, 2015)): vegetables and fruit; bread, cereals, and pastry products; meat, poultry, and fish; milk, milk products, and eggs; sugar and sugar products; soft drinks and alcoholic beverages; and miscellaneous food products. Further, "Avoidable food waste" components were classified into 240 specific food items (e.g., milk, yogurt, tomato, chicken wings, and so on). Whenever possible, brand names were documented.

In the case of packaged food products, the food was separated from its packaging and weighed separately. Packaging information, including expiration date, type of expiration label, net product

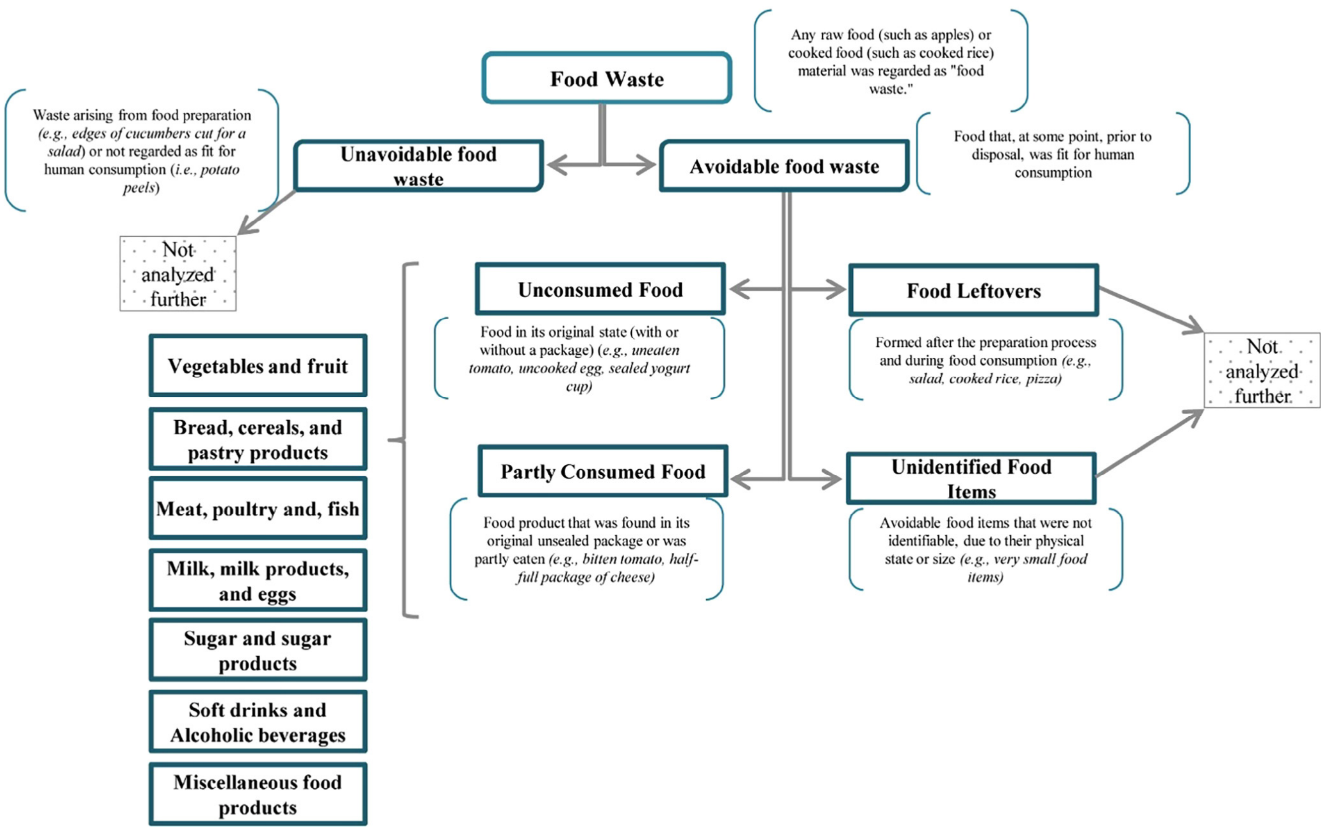

Fig. 3. Classification procedure and definitions employed in current research.

weight, and product price, was recorded. Each "avoidable food waste" item was classified according to its state of consumption:

a. **Food Leftovers** – any food that was modified by cooking, cutting, baking, and so on, was not in its raw state, or was a byproduct of several food products, was considered leftover food. This includes food that has been partially eaten or prepared or food containing various ingredients (e.g., salad), fast food, and commercially prepared meals.
b. **Unidentified Food Items** – avoidable food waste items that were not identifiable, due to their physical state or size (e.g., unrecognized food leftovers).
c. **Partly Consumed Food** – food products that were found in their original unsealed package or were partly eaten.
d. **Unconsumed Food** – food in its original state (with or without a package).

Following the principle of "what you see is what you get," the distinction between unconsumed and partly consumed food was based on its observed state rather than its assumed state. According to this rule, a single uneaten tomato, a single uncooked egg, a single sealed yogurt cup, and so on, were all regarded as "unconsumed food". This is in contrast to Lebersorger and Schneider's (2011) proposition that food that is usually sold bunched should be classified as partly consumed. A food product that was found in its original sealed package was also classified as unconsumed food.

4. Results and discussion

4.1. Household waste composition

In total, 1257 waste bags were analyzed during the study. One hundred and twenty-two households produced seven bags, fifty-five households produced six bags, fourteen produced five bags, and one household produced three bags. This was equal to 2543.56 kg of household waste. Fig. 4 shows the household waste composition by waste stream.

The daily generation rate of household waste in our study is 0.573 kg per capita, compared to 1.7 kg at the national level (CBS, 2016). Yet this comparison to Israeli national statistics should be made with caution. First, the national reports refer to mixed MSW, and do not distinguish between household, commercial, and yard waste. Second, our sample consists of middle-class households and hence does not, necessarily, represent the general population. Still, the fact that household waste in the current study may comprise only one-third of the total MSW might have major policy implications and should be further analyzed in future research.

4.2. Food waste composition

The average total food waste generation rate was 0.26 kg per capita per day. By weight, food waste accounted for 45%

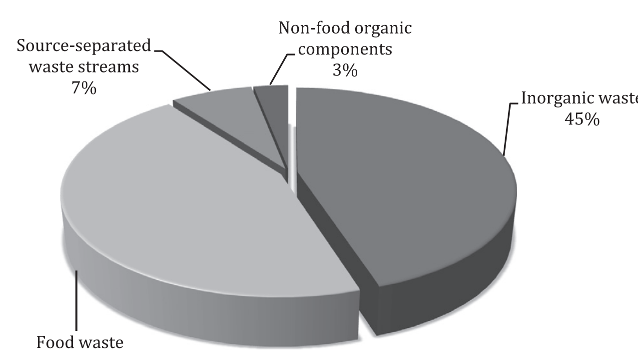

Fig. 4. Household waste composition by waste stream (% by weight).

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

Table 3
Physical food waste surveys at household level from different countries.[*]

Reference	Country	Sample size	Avoidable food waste definition	Share of avoidable food waste out of total food waste (%, by mass)	Predominant avoidable food waste categories (by mass)
Edjabou et al. (2016)	Denmark	1474 households	Edible food that could have been eaten, but instead is disposed of regardless of the reason	56.4%	(1) Fresh vegetables and salads (2) Bakery products
Fehr and Romao (2001)	Brazil	240 participants	Defined as "loss": all items that bypass the kitchen and go from unpacking or storage straight to the waste basket	13.2%	(1) Fruit and vegetables
Gutiérrez-Barba and Ortega-Rubio (2013)	Mexico	41 households	Not reported	Not reported	Not reported
Hanssen et al. (2016)	Norway	220 households	Defined as "edible food waste": material that could have been eaten and was intended for consumption, but was placed in the waste bin for various reasons	58.8%	(1) Fresh bakery products (2) Fruit and vegetables
Lebersorger and Schneider (2011)	Austria	130 households	Whole unused and partly consumed food	56%	(1) Bread (2) Vegetables and fruit
Parizeau et al. (2015)	Canada	222 households	Not reported	Not reported	Not reported
Quested et al. (2013b)	United Kingdom	2660 households	Food and drink, excluding inedible material and packaging. Further excluded are foods that some people eat and others do not (e.g., bread crusts), or that can be eaten when a food is prepared in one way but not in another (e.g., potato skins)	55.2%	(1) Fresh vegetables and salads (2) Drink
Schott and Andersson (2015)	Sweden	486 households	Products that could have been eaten and consist of prepared but uneaten food, food that was left to spoil, and other food products that were disposed of in edible condition	35%	(1) Vegetables and fruit
Schott et al. (2013)	Sweden	2590 households	Products that could have been eaten and consist of prepared but uneaten food that was left to spoil and other food products disposed of in an edible condition	34%	Not reported
Waste Not Consulting (2015)	New Zealand	1402 households	Food that could have been eaten at some point in time. It does not take into account the current state of the item (which could be moldy, or past its 'best before' date), but considers, instead, its past potential	54%	(1) Fresh vegetables and fruit (2) Bakery
Current study	Israel	192 households	Food that is suitable for human consumption	54%	(1) Vegetables and fruit (2) Bread, cereals, and pastry products

[*] Sorted alphabetically by author's name.

Table 4
Avoidable food waste composition by state of consumption (weight).

State of consumption	Weight (kg)	% of total avoidable food waste weight
Unidentified food waste	5.37	0.89%
Unconsumed food	207.59	34.50%
Partly consumed food	197.68	32.85%
Food leftovers	191.09	31.76%
Total avoidable food waste	601.73	100%

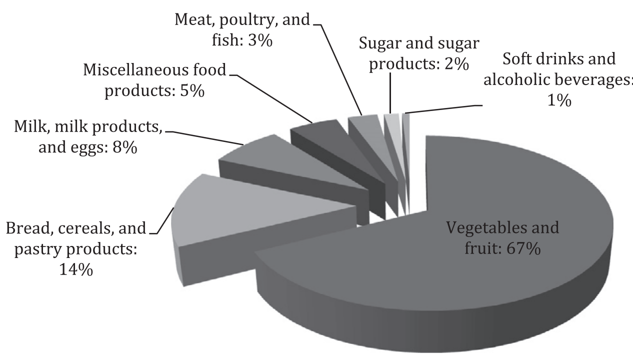

Fig. 5. Share of different food categories in unconsumed and partly consumed avoidable food waste, by weight.

(1,138.57 kg) of total household waste, compared to 44% nationally, according to the Israeli statistics (Seagull Environmental Planning Ltd., 2014). These findings are encouraging, since even though our sample included only middle-class households and a relatively small amount of waste – 2.5 tons as opposed to 8 tons nationally (Seagull Environmental Planning Ltd., 2014), our results are very similar to the Israeli national statistics.

The average avoidable food waste generation rate was 0.136 kg per capita per day. Avoidable food waste was found to constitute 54% (601.73 kg) of total food waste (without packaging). Our results are within the range of previous studies – 54% to 59% (Edjabou et al., 2016; Hanssen et al., 2016; Lebersorger and Schneider, 2011; Quested et al., 2013b; Waste Not Consulting, 2015), as demonstrated in Table 3. Notably, two Swedish studies (Schott and Andersson, 2015; Schott et al., 2013) report quite a small share of avoidable food waste (34–35%). Schott et al. (2013) attribute this gap to the large number of households included in their study. However, this argument does not conform to the data presented in Table 3. Specifically, the correlation between the sample size and share of avoidable waste across studies is insignificant, and if anything suggests a positive, not negative, relation ($r = 0.14$, $p = .74$). Alternative explanations could be cultural differences resulting from food consumption habits or different measurement protocols. Fehr and Romao (2001) reported only a 13.2% share of avoidable food waste, but they used a significantly different definition of the avoidable fraction.

The average weight of avoidable food waste per household ($M = 3.134$, $SD = 2.600$) was found to be higher than the average weight of unavoidable food waste ($M = 2.663$, $SD = 2.068$). This difference was significant [$t(191) = 2.216$, $P = 0.028$].

Unidentified food waste in our study accounted for only 0.47% of food waste. The share of unidentified food waste in the current study was lower than that reported by Lebersorger and Schneider (2011), which was 2% (regarded as a non-classifiable remainder). This finding may imply that collecting waste samples close to their origin on a daily basis indeed preserves their freshness and hence contributes to the sorting and identification of food waste.

4.3. Avoidable food waste composition

The three categories of "state of consumption" were distributed more or less evenly, as shown in Table 4.

The composition of unconsumed and partly consumed avoidable food waste by food category is presented in Fig. 5. The "vegetables and fruit" category was found to be dominant, accounting for 67.5% (273.55 kg) of the avoidable food waste stream. The second most prominent category was "bread, cereals, and pastry products," which constituted 14.13% of total avoidable food waste.

Our findings support previous studies (e.g., Edjabou et al., 2016; Fehr and Romao, 2001; Hanssen et al., 2016; Lebersorger and

Table 5
Relative accuracy analysis.

Waste category*	Level of waste sample according to SWA-Tool recommended limits: Total sample < 10% Leading components < 20%	Relative confidence interval (CI; %)	
		Household basis	Per capita basis
Household waste	Total waste sample	7%	3%
Food waste	Total waste sample	9%	4%
Unavoidable food waste	Leading components	11%	5%
Avoidable food waste	Leading components	12%	6%
Avoidable food waste, *by state of consumption:*			
Unconsumed food	Leading components	15%	9%
Partly consumed food	Leading components	15%	8%
Food leftovers	Leading components	15%	7%
Avoidable food waste, *by food category:*			
Vegetables and fruit	Leading components	14%	8%
Bread, cereals, and pastry products	Other	21%	11%
Milk, milk products, and eggs	Other	25%	14%
Miscellaneous food products	Other	27%	16%
Sugar and sugar products	Other	38%	23%
Meat, poultry, and fish	Other	53%	32%
Soft drinks and alcoholic beverages	Other	61%	34%
Other waste streams:			
Source-separated waste	Other	23%	13%
Non-food organic waste	Other	39%	23%

* Ranked according to household basis CI.

Please cite this article in press as: Elimelech, E., et al. What gets measured gets managed: A new method of measuring household food waste. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.03.031

Table 6
Comparison of sorting rates in different studies.

Source	Type of waste	Man-hours per 100 kg waste sample	No. of sorting categories
European Commission (2004)	MSW	6	29
Toivonen and Sahimaa (2014)	MSW	8	20–30
Liikanen et al. (2016) – 1st study	MSW	24	38
Liikanen et al. (2016) – 2nd study	MSW	16	39
Current study	Food waste	34.40	240

MSW = municipal solid waste.

Schneider, 2011; Langen et al., 2015; Schott and Andersson, 2015; Stenmarck et al., 2016; Waste Not Consulting, 2015), according to which vegetables and fruit, bread, cereals, and pastry products are the most wasted food categories. The findings are also consistent with Israeli national statistics (CBS, 2015), which indicate that fruit and vegetables hold the largest share in households' food expenditures.

4.4. Accuracy estimates

According to the SWA-Tool (European Commission, 2004), the maximum allowable random sampling error for the total results, i.e., relative accuracy, should be below 10%, whereas for leading components of the waste stream, the recommended relative accuracy is less than 20%.

The relative accuracy of our total sample, i.e., total household waste, was 7%, thereby meeting the SWA-Tool requirements (European Commission, 2004). Moreover, the relative accuracy of the total food waste was 9%, compared to 12.1% reported by Lebersorger and Schneider (2011). When calculated on a per capita basis, the relative accuracy of the total food waste was 4% (Table 5). Leading components, i.e., avoidable and unavoidable food waste, unconsumed food, partly consumed food, food leftovers, and vegetables and fruit, were found to be highly accurate. As might be expected with less prevalent waste components, such as "non-food organic waste" and "source-separated waste," the relative accuracy was much lower.

4.5. Technical feasibility and costs

The practice of sorting individual household waste bins is considered very costly and labor-intensive (Dahlén and Lagerkvist, 2008; Edjabou et al., 2016; Jorissen et al., 2015; Langley et al., 2010; Sahimaa et al., 2015). Yet there is little published information on the actual costs of various waste-analysis designs (European Commission, 2004), perhaps because of differences in labor costs between countries, which make comparison difficult. Despite the aforementioned limitations, approximate cost parameters could provide policy makers with valuable data.

In our study, the cost of each kg of waste processed was equal to about $9, while the cost of an hour of work was $27. Roughly 40% of the cost can be attributed to sample collection, and the rest to the sorting process. These figures do not include the recruitment phase, which adds another 5% to the above costs.

As the SWA-Tool (European Commission, 2004) suggests, another important parameter is the sorting rate. Sorting 100 kg of MSW manually should take approximately six man-hours (European Commission, 2004). This indicator is very similar to that reported in the Finnish manual for residual household waste composition studies (Toivonen and Sahimaa, 2014). Liikanen et al. (2016) reported on two MSW composition surveys in which sorting 100 kg took 16–24 man-hours (Table 6).

In our study, the sorting rate was 14.53 kg of waste per hour, and each worker processed approximately 2.91 kg of household waste hourly. Hence, sorting 100 kg took 34.4 man-hours. The allegedly large number of man-hours invested in our study could be explained by the high sorting and classification resolution used compared to regular MSW composition analyses. For example, in our study, the food waste fraction was sorted into seven food categories and then classified into 240 different food items, whereas in MSW composition surveys, waste samples are classified into 30–40 categories only. In addition, the small particle size of organic waste tends to slow sorting (Liikanen et al., 2016). Considering the lack of comparable data regarding both costs and sorting rates, future studies should target these issues, aiming at creating indicative guidelines.

5. General discussion

Cutting food waste is essential to meeting the ambitious Sustainable Development Goal (UN, 2015) of a 50% reduction in per capita food waste production. Yet, managing and reducing food waste require good quantitative measurements. Measuring food waste is a challenging task, mainly due to the lack of a standard method and unified definition system. In this article, we discussed the challenges of measuring food waste with current methods and proposed and tested a new measurement method designed to address these challenges. Specifically, the method physically measures food waste at the household level on a daily basis. In this way, even the highly heterogeneous waste stream is directly connected to its source. The daily waste sample collection implies that the food waste is still fresh when measured, increasing accuracy and improving the ability to categorize a wide variety of food items. Moreover, the fact that organic waste is highly sensitive to decomposition (Jorissen et al., 2015; Langley et al., 2010) due to its physical and biochemical properties suggests the value of our method in solving sampling challenges.

In short, the rationale of the proposed method is focused on the idea that in order to gain insight into food-discarding behaviors, sampling should be performed at the waste bin level (Dahlén and Lagerkvist, 2008). Our method takes this idea a step further by analyzing single waste bags. It, literally, captures food waste at its origin – the point at which it enters the waste stream.

The field test showed that the implementation of our method is indeed feasible. We managed to collect waste samples at the household level while waste remained fresh, and we achieved high levels of accuracy and high resolution of waste classification into different food categories, confirming the hypothesis that analyzing fresh waste samples helps preserve their physical condition, which increases the ability to identify, separate, and classify each waste item, thereby improving accuracy. The success of the field study supports our idea that household-specific food waste generation rates could be accurately measured even in multi-apartment buildings, not only single-family houses. Thus, it addresses Edjabou et al.'s (2016) concern that analyzing individual households is only possible in single-family houses and offers a potential solution to this problem. With the proposed method, the analysis of household food waste in multi-family buildings is not only possible but could also be done with relatively high accuracy.

The ability to connect household food waste to its source also opens avenues for exciting research that could explore the potential relationships between self-reporting techniques (e.g., questionnaires) and physical waste surveys, by conducting both in the same household. One could ask, for example, whether people are accurate in assessing their level of food waste by comparing the two measurements (see Elimelech et al., unpublished results). An interesting recent review (Aschemann-Witzel et al., 2015) outlined behavioral factors related to consumers' food waste, including their motivation to avoid waste, and their food purchasing, storing, cooking, and consumption routines. Further behavioral research is needed to facilitate an understanding of the causes of food waste production. Exploring such questions with current physical surveys methods is practically impossible since, in most of these methods, waste is sampled from collection vehicles or shared waste bins, making it impossible to link the household (the waste source) and the actual waste bags (whether in mixed-use development areas or in multi-apartment buildings; see Jorissen et al., 2015; Koivupuro et al., 2012; Langley et al., 2010). The "Daily Family Waste Collection" method addresses this challenge, making it possible to gather self-reported data and perform a physical survey at the household level, and thus provides a strong tool for assessing these questions.

5.1. Applying the "Daily Family Waste Collection" method

Replicability - The pilot round contributed greatly to our understanding of sorting protocols, and some sorting procedures were adjusted accordingly. Second, the fact that waste samples were collected directly from residents' doorsteps rather than waste bins dictates very close monitoring of sample collection. We found that online documentation of each collection point (i.e., household address) was essential for ensuring that all samples were collected (this proved critical in cases where waste bags were delivered after the designated hour). In addition, it was important to inform our participants of possible delays in collection schedule, to maintain their motivation. This was especially true on Sundays mornings, when the collection extended beyond the usual time frame. We also found that cross-referencing between collection records and sorting records enables instant identification of waste bags with damaged ID stickers.

Scalability - In the current study, we tested the "Daily Family Waste Collection" method in a relatively limited geographical area. This point raises a question regarding the adequacy of this method for studying large household samples. This is an empirical question that should be tested in future studies. Here we suggest some ideas and guidelines for implementing our method in studies of large household samples:

(1) Stratification based on relatively homogeneous socioeconomic strata or geographic locations will enable the employment of relatively small samples in each stratum.
(2) Since each building is generally characterized by a relatively homogeneous socioeconomic index, recruiting participants from several multi-apartment buildings will facilitate stratification and minimize the transport distances of samples due to the relatively limited geographical area.
(3) The collection process can be simplified by the identification of waste bags. Identification technologies such as barcodes, QR codes, or RFID (radio frequency identification) tags can make it easier to identify each household and enable the collection of identified household bags directly from shared waste bins by scanning their codes. This method will simplify the collection process substantially by eliminating the need to collect the bags from each doorstep.
(4) Combining efforts with the national Household Expenditure Survey (conducted by the Central Bureau of Statistics), in which detailed information on households' expenditures and socioeconomic characteristics are collected, primarily through door-to-door interviewing, could contribute to a better understanding of the relationship between households' food expenditure and food waste generation patterns.

5.2. Policy recommendations

The current exploratory study provided several important insights:

The need for unified guidelines – At the macro level, we believe that an important innovation of this article is that it provides decision makers and scholars with information regarding the technical feasibility, cost, and accuracy of the proposed "Daily Family Waste Collection" method. While these aspects are essential from a policy perspective, they are scarcely addressed in scientific and grey literature alike. In order to establish a firm and comparable database, future field research should further explore and document these parameters. We wish to extend the recommendation of Stenmarck et al. (2016) and Williams et al. (2015) to establish commonly agreed-upon metrics for measuring household food waste that will also include a formal standard.**The need for national policy to reduce food waste** – We found that partial information regarding household waste generation rates made it difficult to produce viable comparisons. However, given the large discrepancies between the recorded generation rate of household waste and national MSW statistics, we recommend repeating and confirming these results. The results of our exploratory field survey indicate that large proportions of avoidable food waste include vegetables and fruit. The findings also indicate that 65% of avoidable food waste consists of food that has been partly consumed or not consumed at all. These findings suggest that policy makers may need to focus their efforts on increasing public awareness and improving public practices regarding food management and storage, from shopping habits to home storage and consumption habits (e.g., portion size). Future studies should closely explore local food consumption habits along with other cultural and psychological perspectives and their influence on food waste in terms of quantity and composition.

6. Conclusion

Quantitative measurement of household food waste samples is highly complicated and challenging, yet critically important for waste management. The method proposed here was designed to address two main challenges: connecting the household's food waste to its source and keeping the waste fresh. The field study provided proof of concept for using this method, which has the potential to become a promising tool for addressing the challenges of food waste measurement.

Acknowledgements

We thank the Chief Scientist of the Israeli Ministry of Agriculture and Rural Development for funding this study through research grant no. 20-14-0030 to the PI, Dr. Ron Porat, Department of Postharvest Science of Fresh Produce, Agricultural Research Organization at the Volcani Center. We want to express our appreciation to the Department of Sanitation of Haifa Municipality for providing the operational site for the sorting and assisting with posting the recruitment ads via the municipal Facebook page. We also thank Seagull Environmental Planning Ltd., who provided manpower and logistics for the study. Finally, we are profoundly grateful to Ms. Nirit Avnimelech and Mr. Yuval Marmur for their valuable advice.

References

Aschemann-Witzel, J., de Hooge, I., Amani, P., Bech-Larsen, T., Oostindjer, M., 2015. Consumer-related food waste: causes and potential for action. Sustainability 7, 6457–6477. https://doi.org/10.3390/su7066457.

ASTM International, 2016. Standard test method for determination of the composition of unprocessed municipal solid waste, ASTM D5231-92. American Society for Testing and Materials, West Conshohocken, PA. http://doi.org/10.1520/D5231-92R16.

Bellemare, M.F., Çakir, M., Peterson, H.H., Novak, L., Rudi, J., 2017. On the measurement of food waste. Am. J. Agric. Econ. 99, 1148–1158. https://doi.org/10.1093/ajae/aax034.

Beretta, C., Stoessel, F., Baier, U., Hellweg, S., 2013. Quantifying food losses and the potential for reduction in Switzerland. Waste Manage. 33, 764–773. https://doi.org/10.1016/j.wasman.2012.11.007.

Bradley, P., Thomas, C., Druckman, A., Jackson, T., 2009. Accounting for food waste: comparative analysis within the UK. Proc. ICE - Waste Resource Manage., 5–13 https://doi.org/10.1680/warm.2009.162.1.5.

Bräutigam, K.-R., Jörissen, J., Priefer, C., 2014. The extent of food waste generation across EU-27: different calculation methods and the reliability of their results. Waste Manage. Res. 32, 683–694. https://doi.org/10.1177/0734242X14545374.

Buzby, J.C., Farah-Wells, H., Hyman, J., 2014. The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States. SSRN Electron. J. 121 SRC-. http://doi.org/10.2139/ssrn.2501659.

CBS (Central Bureau of Statistics), 2008. Table B8 – Haifa: Socio-economic Index of Statistical Areas - Citywide and Nationwide. CBS, Jerusalem (in Hebrew).

CBS (Central Bureau of Statistics), 2012. What is the Israeli Middle Class? CBS, Jerusalem (in Hebrew).

CBS (Central Bureau of Statistics), 2015. Monthly income and consumption expenditure in deciles of households by net money income per standard person. Statistical Abstract of Israel 2015. CBS, Jerusalem (in Hebrew).

CBS (Central Bureau of Statistics), 2016. Solid waste collected in local authorities by municipal status and type of treatment. Statistical Abstract of Israel 2016. CBS, Jerusalem (in Hebrew).

Chaboud, G., Daviron, B., 2017. Food losses and waste: navigating the inconsistencies. Glob. Food Sec. 12, 1–7. https://doi.org/10.1016/j.gfs.2016.11.004.

Chen, H., Jiang, W., Yang, Y., Yang, Y., Man, X., 2017. State of the art on food waste research: a bibliometrics study from 1997 to 2014. J. Clean. Prod. 140, 840–846. https://doi.org/10.1016/j.jclepro.2015.11.085.

Dahlén, L., Lagerkvist, A., 2008. Methods for household waste composition studies - a review. Waste Manage. 28, 1100–1112. https://doi.org/10.1016/j.wasman.2007.08.014.

Edjabou, M.E., Petersen, C., Scheutz, C., Astrup, T.F., 2016. Food waste from Danish households: generation and composition. Waste Manage. 52, 256–268. https://doi.org/10.1016/j.wasman.2016.03.032.

European Commission, 2004. Methodology for the Analysis of Solid Waste (SWA-Tool), User Version. 5th Framew. Progr., EU.

FAO (Food and Agriculture Organization), 2013. Food Wastage Footprint: Impacts on Natural Resources—Summary Report. FAO, Rome.

FAO (Food and Agriculture Organization), 2016. Food Wastage Footprint & Climate Change. FAO, Rome.

Fehr, M., Romao, D.C., 2001. Measurement of fruit and vegetable losses in Brazil: a case study. Environ. Dev. Sustain. 3 (3), 253–263.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342. https://doi.org/10.1038/nature10452.

Garcia-Garcia, G., Woolley, E., Rahimifard, S., Colwill, J., White, R., Needham, L., 2017. A methodology for sustainable management of food waste. Waste Biomass Valorization 8, 2209–2227. https://doi.org/10.1007/s12649-016-9720-0.

Girotto, F., Alibardi, L., Cossu, R., 2015. Food waste generation and industrial uses: a review. Waste Manage. 45, 32–41. https://doi.org/10.1016/j.wasman.2015.06.008.

Glanz, R., 2008. Causes of food waste generation in households: an empirical analysis. MSc thesis. Univ. Nat. Resour. Appl. Life Sci. Vienna Cranf. Univ. UK, pp. 14–18.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science (80-.). 327, 812–818. https://doi.org/10.1126/science.1185383.

Gomiero, T., Pimentel, D., Paoletti, M.G., 2011. Is there a need for a more sustainable agriculture? CRC. Crit. Rev. Plant Sci. 30, 6–23. https://doi.org/10.1080/07352689.2011.553515.

Gray, S., 2009. Down the Drain (Project EVA063). WRAP, Banbury.

Gustavsson, J., Cederberg, C., Sonesson, U., 2011. Global food losses and food waste: extent, causes and prevention. Rome Food Agric. Organ. United Nations FAO 37.

Gutiérrez-Barba, B.E., Ortega-Rubio, A., 2013. Household food-waste production and a proposal for its minimization in Mexico. Life Sci. J. 10 (3), 1772–1783.

Haifa Municipality., 2016. Statistical Areas Profile (in Hebrew). Retrieved January 25, 2018, from: <https://www.haifa.muni.il/Services/Strategic-Planning-And-Research/Pages/ProfileStatisticalAreas.aspx>.

Hanssen, O.J., Syversen, F., Stø, E., 2016. Edible food waste from Norwegian households - detailed food waste composition analysis among households in two different regions in Norway. Resour. Conserv. Recycl. 109, 146–154. https://doi.org/10.1016/j.resconrec.2016.03.010.

Hebrok, M., Boks, C., 2017. Household food waste: drivers and potential intervention points for design – an extensive review. J. Clean. Prod. 151, 380–392. https://doi.org/10.1016/j.jclepro.2017.03.069.

Herzog, C., Caspi, N., Nahaissi, M., Biezuner, D., Zfania, A., 2016. Food waste and rescue in Israel: the economic, social and environmental impact. National Report 2015, Leket Israel & BDO, Ra'anana (in Hebrew).

Herzog, C., Caspi, N., Nahaissi, M., Biezuner, D., Zfania, A., 2017. Food waste and rescue in Israel: the economic, social and environmental impact. National Report 2016, Leket Israel & BDO, Ra'anana (in Hebrew).

Hoj S.B., 2012. Metrics and measurement methods for the monitoring and evaluation of household food waste prevention interventions, Master's thesis, Ehrenberg-Bass Inst. Mark. Sci., University of South Australia, North Terrace, Adelaide.

Janssen, A.M., Nijenhuis-de Vries, M.A., Boer, E.P.J., Kremer, S., 2017. Fresh, frozen, or ambient food equivalents and their impact on food waste generation in Dutch households. Waste Manage. 67, 298–307. https://doi.org/10.1016/j.wasman.2017.05.010.

Jorissen, J., Priefer, C., Bräutigam, K.R., 2015. Food waste generation at household level: results of a survey among employees of two European research centers in Italy and Germany. Sustainability 7 (3), 2695–2715.

Koivupuro, H.K., Hartikainen, H., Silvennoinen, K., Katajajuuri, J.M., Heikintalo, N., Reinikainen, A., Jalkanen, L., 2012. Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. Int. J. Consum. Stud. 36, 183–191. https://doi.org/10.1111/j.1470-6431.2011.01080.x.

Kotzer, R., Rosenbloom, A., Tzaban, S., Schuster, A., 2015. Preventing fruit and vegetables food waste. Adam Teva V'Din, Zenovar Ltd., Nekudat Chen (in Hebrew).

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ. 438, 477–489. https://doi.org/10.1016/j.scitotenv.2012.08.092.

Langen, N., Göbel, C., Waskow, F., 2015. The effectiveness of advice and actions in reducing food waste. Proc Inst. Civ. Eng. - Waste Resour. Manage. 168, 72–86. https://doi.org/10.1680/warm.13.00036.

Langley, J., Yoxall, A., Heppell, G., Rodriguez, E.M., Bradbury, S., Lewis, R., Luxmoore, J., Hodzic, A., Rowson, J., 2010. Food for thought?—a UK pilot study testing a methodology for compositional domestic food waste analysis. Waste Manage. Res. 28, 220–227. https://doi.org/10.1177/0734242x08095348.

Lebersorger, S., Schneider, F., 2011. Discussion on the methodology for determining food waste in household waste composition studies. Waste Manage. 31, 1924–1933. https://doi.org/10.1016/j.wasman.2011.05.023.

Liikanen, M., Sahimaa, O., Hupponen, M., Havukainen, J., Sorvari, J., Horttanainen, M., 2016. Updating and testing of a Finnish method for mixed municipal solid waste composition studies. Waste Manage. 52, 25–33. https://doi.org/10.1016/j.wasman.2016.03.022.

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T., 2013. Reducing food loss and waste. World Resour. Inst., 1–40 <http://wwwworldresourcesreport.org>.

Lorenz, B.A.S., Hartmann, M., Langen, N., 2017. What makes people leave their food? The interaction of personal and situational factors leading to plate leftovers in canteens. Appetite 116, 45–56. https://doi.org/10.1016/j.appet.2017.04.014.

Moller, H., Hanssen, O.J., Gustavsson, J., Östergren, K., Stenmarck, Å., Dekhtyar, P., 2014. Report on review of (food) waste reporting methodology and practice. Report from FUSIONS Project. Ostfold Research, Norway. ISBN 82-7520-713-4 978-82-7520-713-3.

Monier, V., Mudgal, S., Escalon, V., O'Connor, C., Anderson, G., Montoux, H., Reisinger, H., Dolley, P., Ogilvie, S., Gareth Morton, G., 2010. Preparatory study on food waste across the EU 27. Final report. European Commission (DG ENV) Directorate C-Industry (Ed.), Contract #: 07.0307/2009/540024/SER/G4.

Neff, R.A., Spiker, M.L., Truant, P.L., 2015. Wasted food: U.S. consumers' reported awareness, attitudes, and behaviors. PLoS One 10, 1–16. https://doi.org/10.1371/journal.pone.0127881.

Nordtest, 1995. Municipal solid waste: sampling and characterisation (No. NT ENVIR 001). Nordtest Method. Espoo, Finland. www.nordtest.info.

Ostergren, K., Gustavsson, J., Bos-Brouwers, H., Timmermans, T., Hansen, O.J., Møller, H., Anderson, G., O'Connor, C., Soethoudt, Han., Quested, T., Easteal, S., Politano, A., Bellettato, C., Canali, M., Falasconi, L., Gaiani, S., Vittuari, M., Schneider, F., Moates, G., Waldron, K., Redlingshöfer, B., 2014. FUSIONS definitional framework for food waste (full report). ISBN 978-91-7290-331-9. The Swedish Institute for Food and Biotechnology, Sweden.

Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. Philos. Trans. R. Soc. B Biol. Sci. 365, 3065–3081. https://doi.org/10.1098/rstb.2010.0126.

Parizeau, K., von Massow, M., Martin, R., 2015. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph. Ontario. Waste Manage. 35, 207–217. https://doi.org/10.1016/j.wasman.2014.09.019.

Parry, A., James, K., LeRoux, S., 2015. Strategies to achieve economic and environmental gains by reducing food waste. WRAP 61. doi:978-1-84405-473-2.

Pekcan, G., Koksal, E., Kucukerdonmez, O., Ozel, H., 2006. Household food wastage in Turkey. Hacettepe University, Statistics Division, working paper series no: ESS/ESSA/006e. FAO, Rome.

Ponis, S.T., Papanikolaou, P.A., Katimertzoglou, P., Ntalla, A.C., Xenos, K.I., 2017. Household food waste in Greece: a questionnaire survey. J. Clean. Prod. 149, 1268–1277. https://doi.org/10.1016/j.jclepro.2017.02.165.

Porpino, G., 2016. Household food waste behavior: avenues for future research. J. Assoc. Consumer Res. 1 (1), 41–51. https://doi.org/10.1086/684528.

Priefer, C., Jörissen, J., Bräutigam, K. R., 2013. Technology options for feeding 10 billion people. Options for Cutting Food Waste. Science and Technology Options Assessment, European Parliament, Brussels, Belgium.

Quested, T., Easteal, S., Ingle, R., 2013a. Methods Used for Household Food and Drink Waste in the UK 2012. WRAP, London. www.wrap.org.uk.

Quested, T., Ingle, R., Parry, A., 2013b. Household Food and Drink Waste in the United Kingdom 2012. WRAP, London.

Quested, T., Luzecka, P. 2014. Household Food and Drink Waste: A People Focus. WRAP, London. www.wrap.org.uk.

Ramukhwatho, F., duPlessis, R., Oelofse, S., 2017. Preliminary drivers associated with household food waste generation in South Africa. Appl. Environ. Educ. Commun. 389. https://doi.org/10.1080/1533015X.2017.1398690.

Richter, B., Bokelmann, W., 2017. Explorative study about the analysis of storing, purchasing and wasting food by using household diaries. Resour. Conserv. Recycl. 125, 181–187. https://doi.org/10.1016/j.resconrec.2017.06.006.

Roodhuyzen, D.M.A., Luning, P.A., Fogliano, V., Steenbekkers, L.P.A., 2017. Putting together the puzzle of consumer food waste: towards an integral perspective. Trends Food Sci. Technol. 68, 37–50. https://doi.org/10.1016/j.tifs.2017.07.009.

Rutten, M.M., Nowicki, P.L., Bogaardt, M.J., Aramyan, L.H., 2013. Reducing Food Waste by Households and in Retail in the EU; A Prioritisation Using Economic, Land Use and Food Security Impacts. Landbouw Economisch Instituut, Wageningen.

Sahimaa, O., Hupponen, M., Horttanainen, M., Sorvari, J., 2015. Method for residual household waste composition studies. Waste Manage. 46, 3–14. https://doi.org/10.1016/j.wasman.2015.08.032.

Schott, A.B.S., Vukicevic, S., Bohn, I., Andersson, T., 2013. Potentials for food waste minimization and effects on potential biogas production through anaerobic digestion. Waste Manage. Res. 31, 811–819. https://doi.org/10.1177/0734242X13487584.

Schott, A.B.S., Andersson, T., 2015. Food waste minimization from a life-cycle perspective. J. Environ. Manage. 147, 219–226. https://doi.org/10.1016/j.jenvman.2014.07.048.

Seagull Environmental Planning Ltd., 2014. National Waste Composition Survey 2012–2013. The Israeli Ministry of Environmental Protection, Jerusalem (in Hebrew).

Secondi, L., Principato, L., Laureti, T., 2015. Household food waste behaviour in EU-27 countries: a multilevel analysis. Food Policy 56, 25–40. https://doi.org/10.1016/j.foodpol.2015.07.007.

SII (Standards Institution of Israel), 1996. Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste, IS 2221. The Standards Institution of Israel, Tel Aviv (in Hebrew).

Smith, P., Gregory, P.J., 2013. Climate change and sustainable food production. Proc. Nutr. Soc. 72, 21–28. https://doi.org/10.1017/S0029665112002832.

Stefan, V., van Herpen, E., Tudoran, A.A., Lähteenmäki, L., 2013. Avoiding food waste by Romanian consumers: the importance of planning and shopping routines. Food Qual. Prefer. 28, 375–381. https://doi.org/10.1016/j.foodqual.2012.11.001.

Stenmarck, A., Jensen, C., Quested, T., Moates, G., 2016. Estimates of European food waste levels. Report from FUSIONS Project. ISBN 978-91-88319-01-2. IVL Swedish Environmental Research Institute, Stockholm.

Toivonen, L., Sahimaa, O., 2014. Opas sekajätteen koostumustutkimuksiin (Guide for Mixed Waste Composition Studies). Finnish Solid Waste Association, Helsinki (in Finnish). <http://jly.fi/Opas_sekajatteen_koostumustutkimuksiin.pdf> (accessed 24 Aug 2017).

UN (United Nations), 2015. Transforming our world: the 2030 agenda for sustainable development. A/RES/70/1, 21 October. UN, New York.

UN (United Nations), 2017. World population prospects, the 2017 revision. Department of Economic and Social Affairs, P.D., Population Estimates and Projections Section, ed. UN, Rome. <https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf>.

Ventour, L., 2008. Food Waste Report: The Food We Waste. WRAP.

Visschers, V.H.M., Wickli, N., Siegrist, M., 2016. Sorting out food waste behaviour: a survey on the motivators and barriers of self-reported amounts of food waste in households. J. Environ. Psychol. 45, 66–78. https://doi.org/10.1016/j.jenvp.2015.11.007.

Waste Not Consulting, 2015. New Zealand Food Waste Audits, National Food Waste Audits 2015. Prepared for WasteMINZ, Auckland.

Williams, H., Wikstrom, F., Otterbring, T., Lofgren, M., Gustafsson, A., 2012. Reasons for household food waste with special attention to packaging. J. Cleaner Prod. 24, 141–148.

Williams, I.D., Schneider, F., Syversen, F., 2015. Editorial. The "food waste challenge" can be solved. Waste Manage. 41 SRC-, 1–2.

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O'Connor, C., Östergren, K., Cheng, S., 2017. Missing food, missing data? A critical review of global food losses and food waste data. Environ. Sci. Technol. 51, 6618–6633. https://doi.org/10.1021/acs.est.7b00401.

Zorpas, A.A., Lasaridi, K., 2013. Measuring waste prevention. Waste Manage. 33, 1047–1056. https://doi.org/10.1016/j.wasman.2012.12.017.