Resources, Conservation & Recycling 130 (2018) 140–151

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

The tree structure — A general framework for food waste quantification in food services

Mattias Eriksson[a,b,*], Christine Persson Osowski[c], Jesper Björkman[b], Emma Hansson[d], Christopher Malefors[b], Emelie Eriksson[e], Ranjan Ghosh[f]

[a] Department of Energy and Technology, Swedish University of Agricultural Science, Box 7032, S-75007 Uppsala, Sweden
[b] Matomatic AB, Ulls väg 29C, S-75651 Uppsala, Sweden
[c] Department of Food, Nutrition and Dietetics, Uppsala University, Box 560, S-75122 Uppsala, Sweden
[d] Department of Economics, Swedish University of Agricultural Science, Box 7013, S-75007 Uppsala, Sweden
[e] Catering Services Unit, Technical Office, Sala Municipality, Box 304, S-73325, Sala, Sweden
[f] Indian Institute of Management, Vastrapur, Ahmedabad 380015, Gujarat, India

A R T I C L E I N F O

Keywords:
Food waste quantification
Framework
Canteen
Restaurant
Methodology
Tree structure

A B S T R A C T

Food waste in the food services industry has been identified as an important unsustainability hotspot, but standardised methods for food waste quantification are lacking. Existing studies on waste quantity assessments have several limitations, such as short and infrequent quantifications times, large methodological variations ranging from physical measurements to visual observations, and lack of comparability across catering unit types. Since lack of comparable waste figures can lead to error-prone analysis, a general framework is needed for waste quantification in food services. This paper presents one such framework that allows data comparisons when overlapping observations are included. The framework was tested in six case studies in professional (public and private) catering units in Sweden. Data were collected from different schools, elderly care homes and hotels and fitted into the framework. The results from these case studies indicate that the framework enables catering units to focus waste quantification on their individual problem areas. It also provides the possibility to extend waste quantification over time without any loss of generalisability. A graphical representation of the framework fits the traditional tree structure and was found to act as a suitable foundation for food waste quantification in food services by structuring collected data. In order to fully utilise the potential of the tree structure, it should be supplemented with precise definitions to create a catering food waste quantification standard.

1. Introduction

Although food waste seems like a simple problem, the solution “to just stop throwing food away” is much more complex. The food waste issue gains in complexity when linked to the three pillars of sustainable development: economic, social and environmental. Although reducing food waste will not automatically result in sustainable development, it can make an important contribution. Food waste is associated with substantial losses of money (FAO, 2013) and natural resources (Steinfeldt et al., 2006; Garnett, 2011; Scholz et al., 2015), but also has moral implications in relation to food security (Stuart, 2009; Godfray et al., 2010; FAO, 2012). In recent times, industry (Tesco, 2014), governments (Rutten et al., 2013) and international organisations (UN, 2016) have initiated waste reduction programmes. Reducing food waste is also less controversial than, for instance, reducing meat consumption or increasing productivity by expanding the use of genetically modified organisms. Since food is wasted for a large number of reasons and by different actors in the food supply chain, it is difficult to find a ‘quick fix’ solution. Food can also be wasted as a result of measures to increase profits or protect public health. In many countries, food waste creates a problem if it is landfilled or left in illegal dumping sites. In other countries, Sweden included, landfilling of organic waste is prohibited (Ministry of the Environment and Energy, 2001) and surplus food is considered a resource that can be used for biogas production or for feeding people in need (Eriksson et al., 2015; Eriksson and Spångberg, 2017). It is therefore not the wasted food that is the prime concern, but the wasteful behaviour that results in unnecessary food production in the first place.

Before food wastage can be reduced, it is necessary to identify the quantities of waste generated. This requires accurate waste estimation (Eriksson, 2012, 2015) and is an essential first step in evaluating the effect of any food waste reduction measure. However, international

* Corresponding author at: Department of Energy and Technology, Swedish University of Agricultural Science, Box 7032, S-75007 Uppsala, Sweden.
E-mail address: mattias.eriksson@slu.se (M. Eriksson).

https://doi.org/10.1016/j.resconrec.2017.11.030
Received 23 September 2017; Received in revised form 29 November 2017; Accepted 30 November 2017
0921-3449/

studies of food waste in food services lack accurate data. One survey showed that only about half of Swedish schools measure food waste at a frequency of one week per semester or higher (School Food Sweden, 2013). In studies in the UK, food waste was quantified for two days in three hospitals (Sonnino and McWilliam, 2011) and for 28 days in one hospital (Barton et al., 2000); in studies in Sweden for two days in four kitchens (Engström and Carlsson-Kanyama, 2004); in Switzerland for five days in two kitchens (Betz et al., 2015); in Portugal for 471 school meals during one month (Martins et al., 2014); in the United States for five days in one kitchen (Byker et al., 2014); and in Finland for one week in 55 kitchens (Katajajuuri et al., 2014). Such small-scale measurements may produce results that are inconclusive and biased, making any interpretation error-prone.

Moreover, the method used for quantifying food waste and the scope of previous studies vary. Some studies are based on visual observations (e.g. Connors and Rozell, 2004; Hanks et al., 2014), while others use physical measurements. Engström and Carlsson-Kanyama (2004), in their study of two school kitchens and two restaurants, categorised food waste into storage losses, preparation losses, serving losses, plate waste and leftovers. All the losses were then divided into food item types. Betz et al. (2015) followed broadly Engström and Carlsson-Kanyama's method, with the addition of making a distinction between gross and net weight. In Sonnino and McWilliam's (2011) study of food waste in hospitals, all food, containers and plates were weighed before and after meals to calculate the waste. One meal was studied in great detail, while all leftover individual food items on the plate were separated, grouped and weighed. A similar approach was used by Martins et al. (2014) in their study of plate waste in Portuguese primary schools, i.e. the plates were weighed before and after the meal. Barton et al. (2000) studied a hospital's plate and tray waste by measuring all food supplied and wasted during a 28-day period and weighing the total remaining food at the end of each meal. Each food item was also weighed separately. Food waste was calculated as the difference between food served and food recovered at the final weighing. Byker et al. (2014) studied food waste in a school where, after the students had completed their meal, the research team collected lunch trays and separated food and beverages into respective bins, which were weighed on a digital scale. In a study by Katajajuuri et al. (2014) of waste in the Finnish food sector, the waste generated during cooking and serving and leftovers from the customers were weighed and noted. Hackes et al. (1997) studied food waste in the American elderly sector by collecting and measuring all uneaten food items from the residents in a retirement community after each meal over seven days. The weight and the volume of the waste were computed on a per meal, per day and per week basis. A similar study of plate waste was conducted by Hayes and Kendrick (1995) at five American elderly catering centres, where waste was collected from the plates and separated by menu item. The percentage of food waste was calculated, using serving size to determine total mass of food served.

There is clearly a need for a more general framework that enables comparisons of food waste quantifications. For instance, in some studies, quantification of food waste is an essential element (e.g. Kallbekken and Sælen, 2013) but the methods used are not described. In the majority of the studies cited above, the measurements were time-consuming and almost exclusively performed by researchers. In order to get actors in the food service sector to conduct measurements *themselves,* the method must be time-efficient in terms of learning and preparation and implementation. The idea of a *framework* derives from the belief that quantification can be performed more easily. Measurement of food waste in supermarkets represents a good example, where large-scale studies have been conducted using high-precision data collected by the supermarkets themselves (e.g. Eriksson et al., 2012, 2014, 2015, 2016a,b, 2017b; Lebersorger and Schneider, 2014; Brancoli et al., 2017).

Against this background, the aim of the present study was to develop and test a methodological framework for food waste quantification in food services that could demonstrate the complex nature of food waste, while increasing the transparency of quantification methods. The framework developed was applied to a set of case studies, where data were fitted to test the generalisability. The framework was developed with the focus on Swedish food services, but the general structure should also be applicable in other countries and sectors. The framework is described in Section 2 of the paper, while the cases and the results from case analyses are presented and discussed in Section 3. Section 4 presents some conclusions from the work.

2. Materials and methods

The first step was to develop a general framework for food waste quantification in food services. The next step was to apply the framework to several case studies providing actual food waste data from different food service organisations. This might seem like a linear process (cf. Papargyropoulou et al., 2016), but in reality the development process involved several cycles of testing and redeveloping.

2.1. Context and rationale

In the Swedish food services sector (including both public and private catering units), environmental issues related to food waste are a growing concern. This could be due to the high levels of food waste in Sweden. According to the Swedish Environmental Protection Agency (SEPA, 2016), 70 000 t of food waste are generated every year in the Swedish public food service sector, including schools, pre-schools, elderly care homes, hospitals and prisons. The amount generated by private restaurants is similar, 66 000 t per year. This is much lower than the corresponding estimate for Swedish households (700 000 t per year), but since households serve a much larger volume of food, comparisons of absolute values give a limited view of the problem and therefore relative waste values should be considered. According to a recent study by Eriksson et al. (2017a), relative waste in 30 kitchens in the Swedish municipality of Sala was 75 g per portion served, or 23% of the mass of food served. Other studies of relative waste levels in similar types of catering establishments indicate what could be considered a normal level, although the studies differ in scope and refer to different times and geographical places. The four restaurants in Stockholm investigated by Engström and Carlsson-Kanyama (2004) wasted on average 20% of delivered mass, corresponding to 92 g per portion served, and the two kitchens in Switzerland investigated by Betz et al. (2015) wasted 10.7% and 7.7%, corresponding to 91 and 86 g per portion served.

In the absence of simpler methodology, Jacko et al. (2007) argue that aggregated methods to measure plate waste (e.g. weighing bins of collected waste) are more accurate than selective methods (e.g. weighing each plate/tray separately), as they are less time-consuming and hence more suitable for long-term data collection performed by kitchen staff. However, there are obvious advantages of achieving the higher resolution in data that selective methods can provide, e.g. they can enable investigation of factors actually causing food waste (as done by Steen, 2017). Such studies are very few in number, perhaps because of the lack of a common standard for quantifying and reporting food waste. This makes results from different organisations difficult to compare. The WRI's Food Loss and Waste Accounting and Reporting Standard (World Reasource Institute, 2016) could be used, but it is possibly too general to exactly identify a reasonable trade-off between 'resources used' for waste quantification and food production. Although food services can, in theory, follow the WRI approach, the data are generally not comparable across organisations, unless some more detailed methodology is applied. In this context, we attempted to develop a more generalisable quantification framework, as is described in the ensuing sub-sections.

2.2. Criteria for the framework

The following criteria were used in development:

- The framework had to be general enough to be used in any kind of catering unit where food is transformed from raw ingredients into meals
- The framework had to permit categorisation and comparison of results from different types of quantification methodologies
- The framework had to be flexible enough to allow both in-depth quantification and less time-consuming quantification, in order to suit the needs of researchers and of kitchen staff with limited resources, respectively. It also had to allow changes over time, so that a catering unit could improve its quantification without making previous data obsolete
- The framework had to align with previous suggested methodologies, especially the concepts presented by Papargyropoulou et al. (2016) and World Reasource Institute (2016), since these are based on sound and easily accepted principles. However, it had to build further on a specific part of the food supply chain, bringing these principles closer to the actual user.
- The framework had to have a user perspective and therefore be developed in such a way that it could be communicated with the target group, i.e. kitchen staff and managers.

2.3. Case study testing

In order to test the framework developed, data were collected from different types of food services. The cases were selected to represent different kinds of quantification practices and public food services in the Swedish municipalities of Sala, Gothenburg and Uppsala and two hotels in the Uppsala-Stockholm area. Most of the data were taken from the three municipal authorities, as they manage school kitchens, preschools and elderly care homes. Some of these are production kitchens and some are satellite kitchens, and eating can take place in a large dining hall or in smaller units. These municipal organisations are 'non-profit', which means that their waste quantifications are typically based on environmental concerns or political goals rather than profit optimisation. Remaining data were sourced from private businesses which, on the other hand, have clear economic motives to keep food waste low. Although only a few such cases were included, they represent important ways of quantifying food waste.

2.4. Framework development – the tree structure

c of branches. Each level represents a particular type of data and every node is a potential point of observation. It is also possible to skip a node and make the point of quantification at a sub-node, but with the consequence that an aggregated level might be the lowest common denominator where two catering units can be compared. The framework contains the following eight quantification levels, where the later levels make up sub-categories of a previous level:

- Catering unit: The unit that produces food for one or many serving units.
- Serving unit: The point where the prepared food meets the guest/consumer and the organisational unit for waste quantification, often the catering unit itself when there is only one serving unit per catering unit.
- Meal: The meal basically depends on the time of the day, typically breakfast, lunch and dinner. This level could also be recorded as a time stamp when no distinct meals are served, but the same menu is offered irrespective of the time.
- Process: The preparation or serving process is when the waste has been generated, typically during preparation, at serving or as leftovers on a plate. In larger catering units where different processes are likely to take place in separate kitchens, the exact processes occurring might be easier to define than in a small catering unit where all processes take place in a limited amount of time and space.
- Meal component: In some processes, the meal component is predefined, but in the later processes it is common to separate components like salad, sauce, side-orders, main dish and so on.
- Meal sub-component: This is only applicable if there are sub-components, as when two or more main components are served, e.g. one with meat and one vegetarian.
- Food type: Since the meal component just defines the roles of different food types in a meal, there is in some cases a need to quantify the exact type of food wasted. Since this level of quantification is very similar to the meal sub-component, it is likely that only one of these levels will be used. However, the difference in comparison with the meal sub-component level is that the vegetarian main component is likely to be defined as vegetables and possibly mixed up with salad or cooked vegetables as a side-order, which means that the use is not really captured.
- Sub-food type: Food types can also be categorised in more than one way and there might be a need to quantify data on different levels. For example, root vegetables are a food type including the sub-food types carrots and potatoes. Food can obviously be categorised in several ways and on more than two levels of aggregation, but the framework only displays two levels for simplicity.

For each of the quantification levels, there are a large number of possible observations to be recorded. Table 1 exemplifies a number of potential quantification categories. These examples are provided since any quantification methodology must obviously be usable for practical quantification. In addition, the tree consists of organisational information, metadata about the catering and serving units and the reference bases quantified in order to calculate a relative key figure from recorded masses of food waste.

In order to make food waste comparable over time and between different catering units, there is a need for *relative* key figures. Here we identified two different key figures with different possibilities and limitations. The first, and possibly most useful, approach is to present the waste as mass per guest served. The number of guests should be

Table 1
The food waste quantification framework, with examples of observations that could fit in each level of the framework.

1 Catering unit	2 Serving unit	3 Meal	4 Process	5 Component	6 Sub-component	7 Food type	8* Sub-food type
School	Satellite canteen	Breakfast	Receiving	Main component	Main comp. meat	Meat, fish and egg	Beef
Hospital	Dining hall	Lunch	Storage	Side order	Main comp. fish	Vegetables	Pork
Hotel	Classroom	Dinner	Preparation	Salad	Main comp. vegetarian	Fruit and berries	Poultry
Restaurant	Care unit	Snack	Safety margin	Sauce	Side-order bread	Root vegetables	Fish
	Room service		Serving	Diet	Side-order potatoes	Potatoes Cereals	Beans
	Packed lunch		Buffet	Desert	Carbohydrate-rich component	Dairy	Lentils
			Plate scrapings		Side-order vegetables		Egg
			Dishwasher sieve				Cheese

* Level 8 is included to illustrate the possibility of categorising food types on further levels of aggregation.

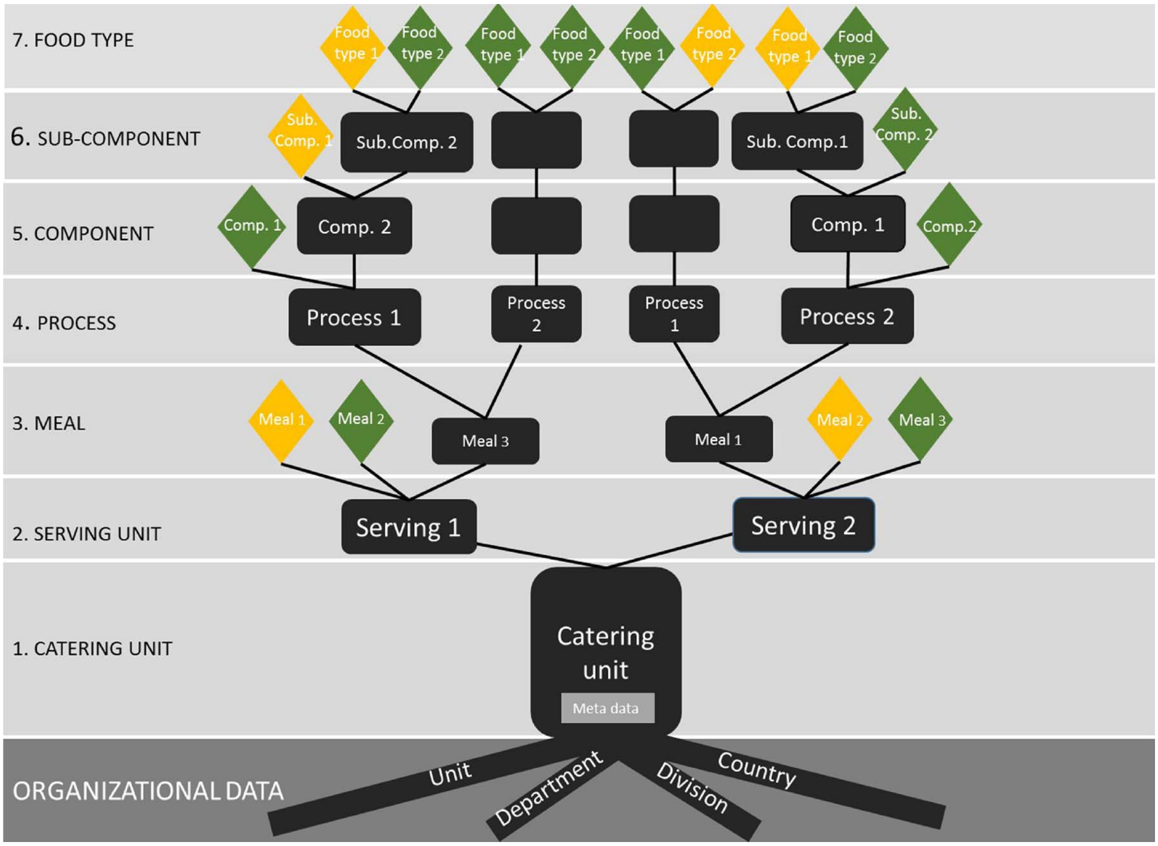

Fig. 1. The food waste quantification framework, illustrated as a tree.

fairly easy to quantify accurately through a payment system or by counting the number of plates. This provides an easy key figure that gives a good overall perspective. The other key figure we identified is percentage waste in relation to mass of individual or aggregated waste categories served. Since this key figure can be used to highlight specific waste flows that are not captured by the mass per guest, it can be an efficient tool for problem analysis and progress follow-up. The downside is that it requires quantification of served food with the same resolution as wasted food. This is potentially very time-consuming and the accuracy may suffer as a consequence, since estimates of mass served might be used instead of actual quantities. However, if there are extra resources available, it is possible to quantify served food with high accuracy, e.g. for scientific purposes. There is also the possibility to use the number of guests with the same type of resolution as for the mass of food served, for instance whether the meals are served as a free choice or set menu. However, practical limitations should be the main consideration in finding the best compromise for acquiring the best data with the least effort, and this compromise is likely to be highly influenced by how the food is served in each establishment.

Since many canteens, hotels and restaurants are part of a larger organisation where one catering unit may produce food for several serving units, there is a need to separate food cooking from food serving, but both should be included in order to make information exchange possible. One example of this kind of structure is a central catering unit that sends hot food to satellite serving units far away. Another example is large restaurants that have different dining areas where different food types are served. In such cases, different levels and categories of food waste will be generated in the different satellite serving units or dining areas, but the preparation losses will be generated in the production kitchen. It must therefore be possible to cluster kitchens and dining halls in order to evaluate the performance of the whole cluster, especially since information sharing is very likely to be vital for efficient production planning and waste reduction. Therefore, the point of quantification is the *serving point* rather than the *point of production*, with the production (catering) unit as the defining component in the cluster of serving units.

The remaining information that can be collected within our framework are metadata about the catering unit. There is practically no limit on the type of information that can be collected, but the most obvious are: information about the type of consumers (e.g. school pupils, hotel guests), number of seats in a dining hall, gender of the catering and serving staff and anything that might have a direct or indirect influence on food waste. All available metadata should be assigned to each data point, in order to make deeper analyses possible. Free text comments could be seen as a metadata point specific for each mass observation.

The organisational structure of the company or public body that runs a food service is also a vital type of metadata. However, we considered this to be a separate part of the system, since the organisational structure is likely to be a hierarchy of several levels of units, departments and divisions, where aggregations and comparisons of all these organisational levels might be of interest. Both the organisation and the metadata will possibly shift over time due to reorganisations, because catering units are renovated or if there is a shift in customers.

In order to illustrate the framework, a tree is used to simplify the structure and make it user-friendly (Fig. 1). In this illustration, the trunk represents the serving unit and, if there are several serving units connected to a catering unit, the tree has several trunks. The branches that can be placed on different levels represent all the different subcategories of waste quantification. At the end of each branch there is a leaf symbolising the data point. These can be either active (green leaf) meaning that they are used by the catering unit in question, or they can be passive (yellow leaf) meaning that this category of waste exists, but is not included in the quantification. This means that each branch should end in a leaf, either green or yellow. In this illustration, inscriptions or signs on the tree trunk/s represents the metadata on the

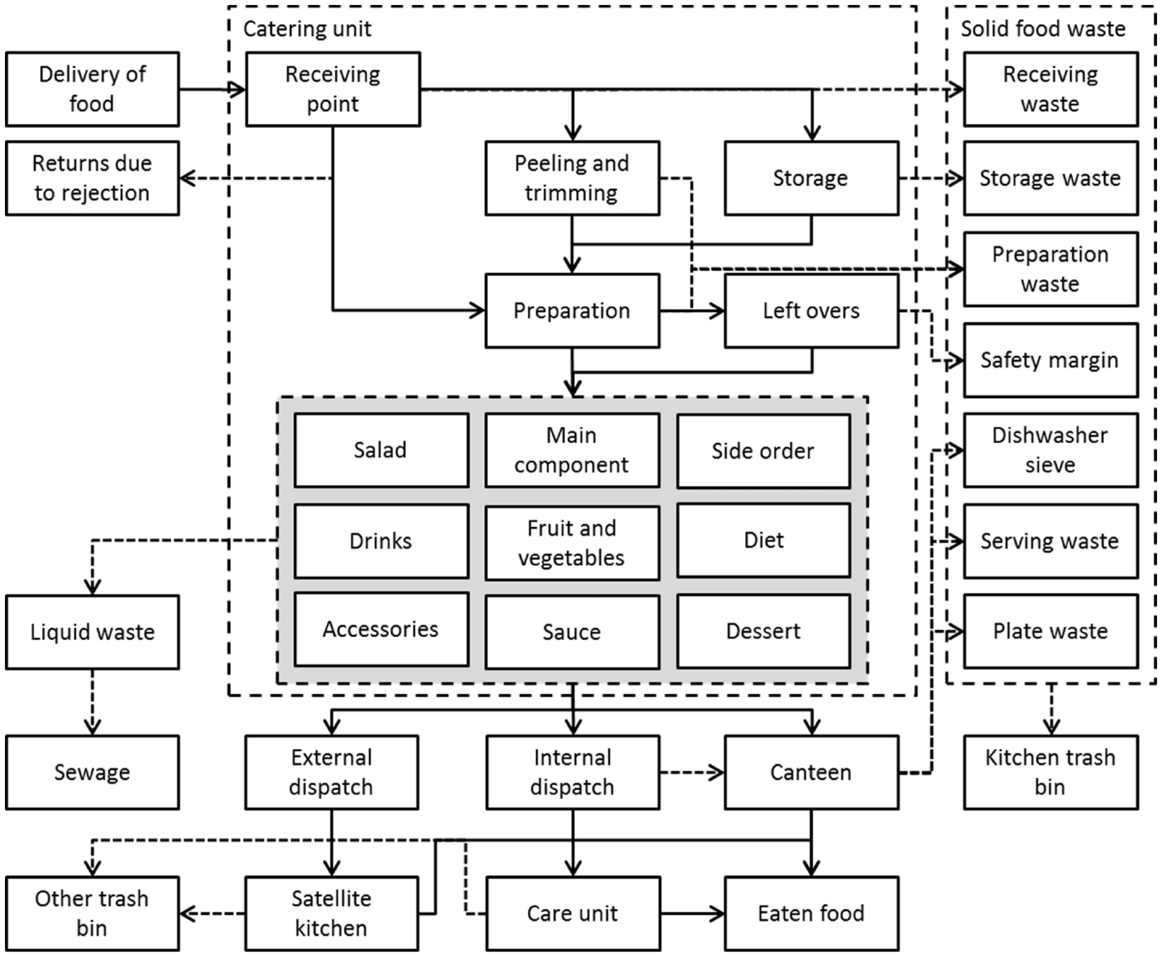

Fig. 2. Schematic figure of the mass flow in a catering establishment, illustrating the process-based waste categories. The grey area indicates food prepared in the production (catering) unit, but sent out to be eaten in different places.

serving unit/s and the hierarchy of the organisation, where the catering unit is represented as a root system.

2.5. Identification of useful definitions and specifications

Since the tree structure applies only to the very end of the food supply chain, where food is cooked and consumed, the framework has a clear focus on prepared food rather than the raw ingredients. This makes the framework less comparable with the rest of the food supply chain, but the aim is to make *catering units* comparable, rather than comparing catering establishments with farms. This is a limitation, but it makes it easier to handle the inconsistencies described by Chaboud and Daviron (2017), since many problems with definition arise when different stages in the food supply chain are compared. Therefore, the definition of food waste used by FUSIONS (Östergren et al., 2014) was chosen for the framework because of its simplicity, since both edible and inedible parts are considered food waste. Since this is at the very end of the food supply chain, the definition used by FAO (2011) could also be used, with the difference that a mix of waste and losses will be quantified.

The different categories of data are in some cases very flexible and can be defined by the user in order to suit the specific context. However, the process data category may need more specification, since this is obvious from a research or from a user perspective. Therefore, Fig. 2 illustrates the different flows in catering establishments and how the different process-orientated waste categories are dependent on where in the process they occur.

Since the mass flow of waste can be of significant importance for the mass flow of the whole catering unit, Fig. 3 helps illustrate where the point of observation for the served food is located. It can appear strange to not select one of the end-points in the process as a base of reference, but we selected food served as the reference point for two reasons. First, it is the only step in the process where only the food served on a particular day appears. Some of the steps prior to serving may take place days beforehand, due to long preparation and storage times. Here, leftovers also play a role since they can be seen as prepared food until they are served, which is likely to be a day or two later than when they were cooked. The second reason is practical: it is much easier to quantify the amount of food served than the amount taken or eaten. It would also be difficult to recalculate the mass of food served into mass of food eaten due to addition and loss of water in the cooking process. Moreover, according to Eriksson et al. (2017a) most of the waste occurs post-serving, making the later stages more important for food services.

3. Results and discussion

3.1. Case studies to test the framework

Data from several case studies were fitted into the framework in order to test whether it can handle and bring structure to quantification methods already in place. The cases involve data from elderly care units in Sala municipality, school canteens in Malmö and Uppsala municipalities, pre-schools in the city of Gothenburg, two university campus restaurants in Uppsala and three hotels in the Uppsala-Stockholm region.

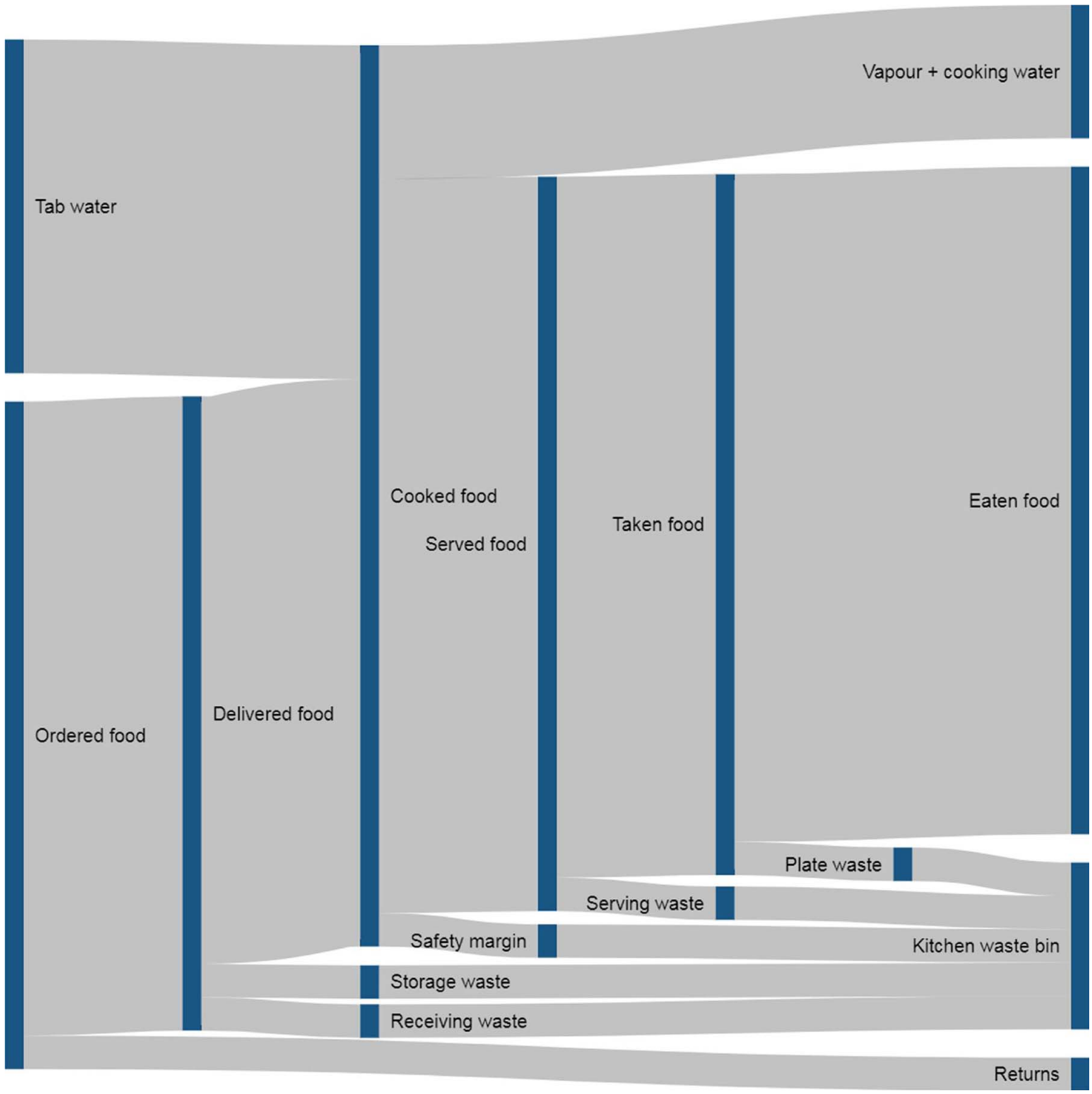

Fig. 3. Sankey diagram illustrating the different mass flows through a catering unit. Liquid waste and dispatched food are omitted for the sake of simplicity.

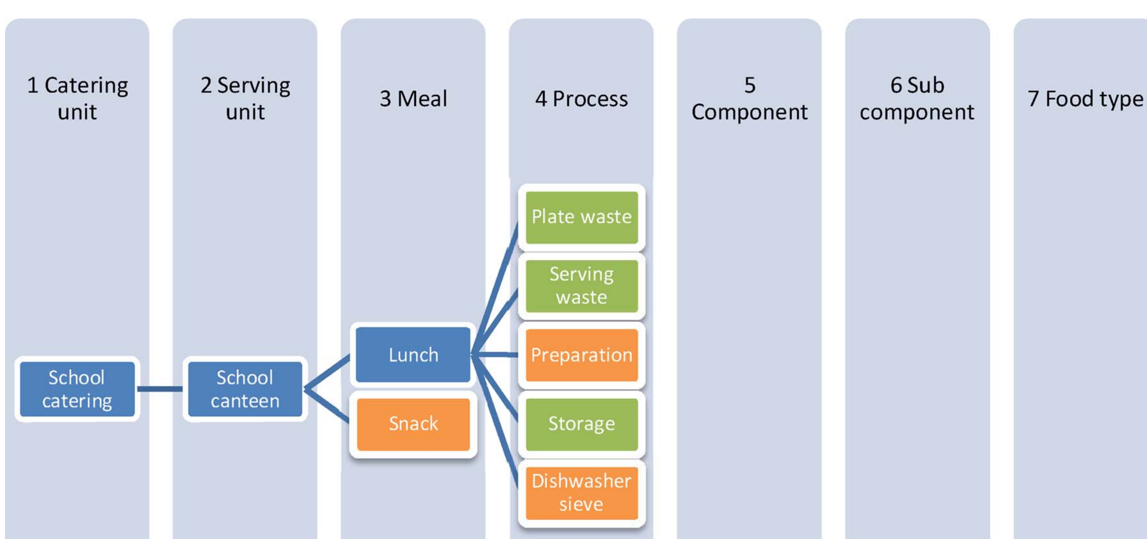

Fig. 4. School canteen in Uppsala municipality. Blue areas in the diagram represent parent nodes to other nodes; orange nodes represent those present, but not quantified; and green nodes represent the end-nodes, which are quantified. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

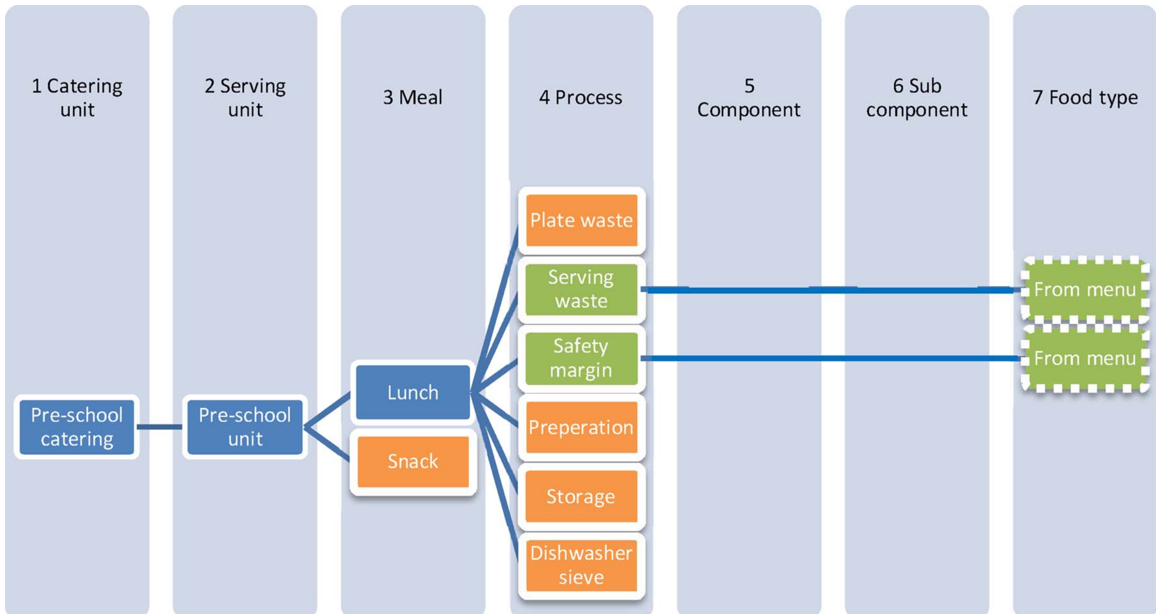

Fig. 5. Typical pre-school in the municipality of Gothenburg.

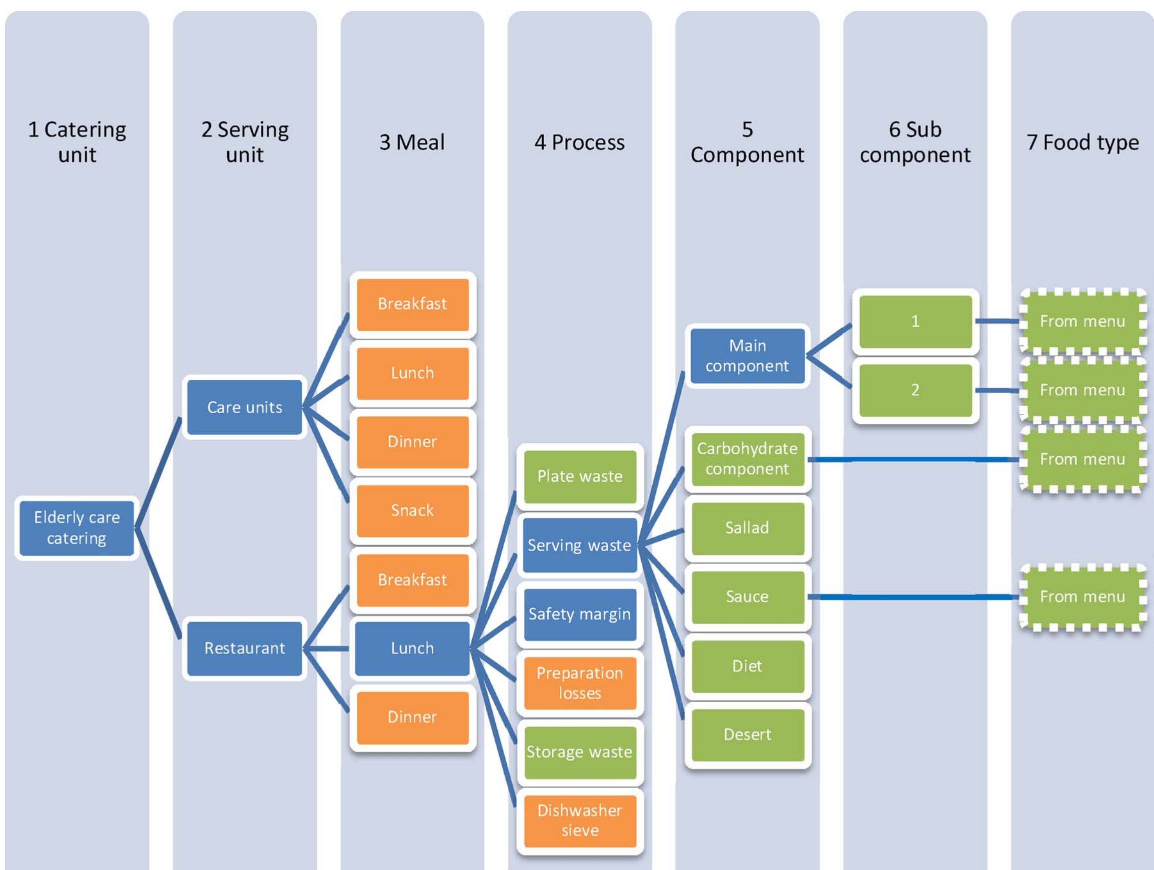

Fig. 6. Catering unit in an elderly care unit in Sala municipality that serves food to a restaurant and to the care unit, with the safety margin aggregated with the serving waste when quantified, for practical reasons. The food types are not part of the quantification, but can be connected through the menu in order to generate data on the type of food wasted.

3.1.1. School canteens in Uppsala municipality

Data from the municipality of Uppsala were employed by Steen (2017), who used schools to model risk factors of food waste generation. Since Uppsala municipality uses a similar structure to collect food waste data in all its school canteens, Fig. 4 can be used to depict several similar catering units. In this example the catering unit only supplies its own canteen, which serves lunch and snacks (typically fruit and sandwiches). In addition to the mass of wasted food, the catering unit records the number of pupils served lunch.

Since this case has quite a simple structure, with only one serving unit attached to the catering unit and only one meal included in waste quantification, the quantification fits well into the tree structure. Since

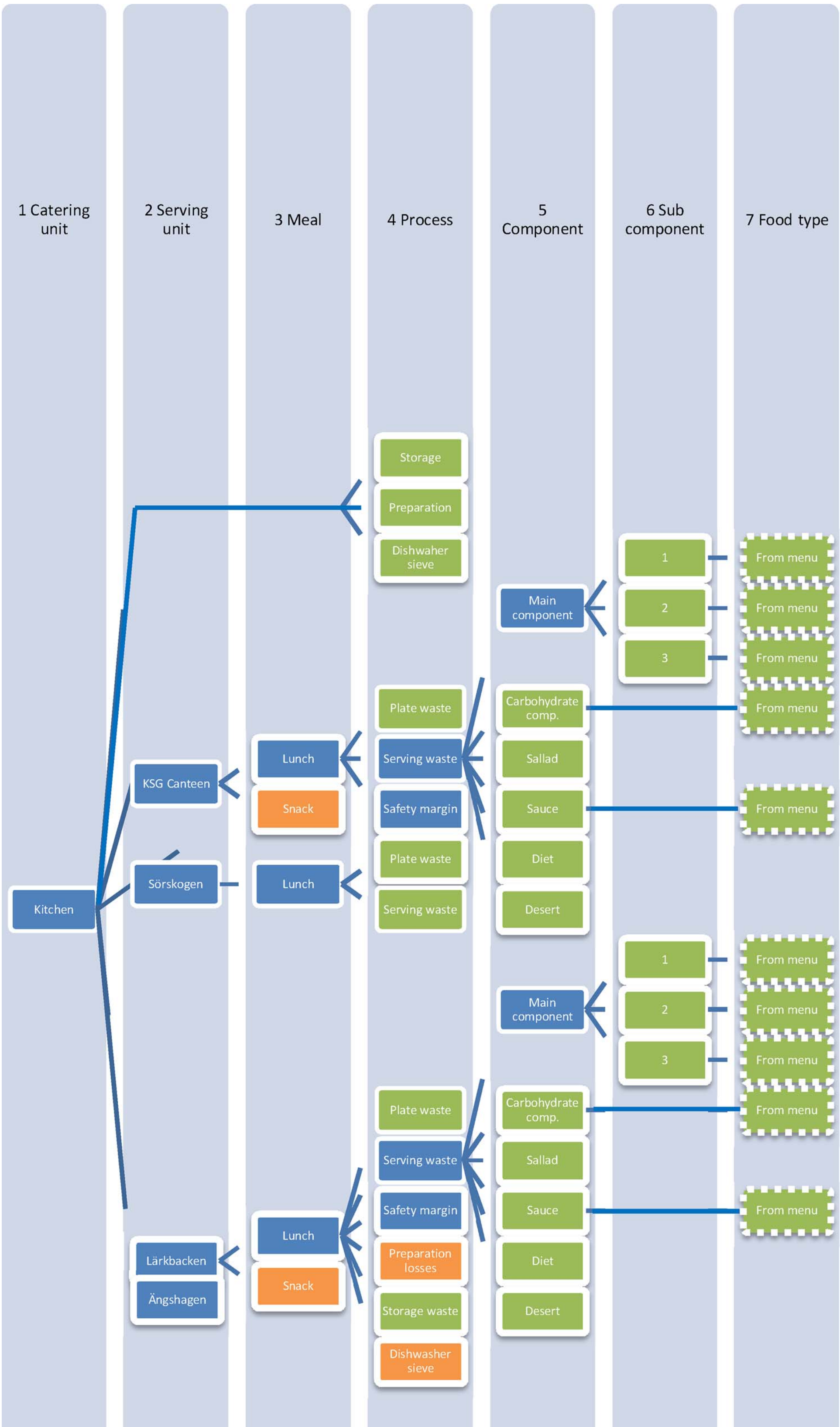

Fig. 7. Catering unit in a secondary school in Sala municipality that serves food both to a restaurant and to two satellite school canteens, with the safety margin aggregated with the serving waste when quantified, for practical reasons. The food types are not part of the quantification, but can be connected through the menu in order to generate data on the type of food wasted.

waste quantification only includes tree observations on the same level (the process level), there is not much need for using the framework for this quantification, but the structure can be useful if waste quantification is increased, in order to set out the direction for the additional observations.

3.1.2. Pre-schools in the city of Gothenburg

Data from pre-schools in central Gothenburg use the Gothenburg model (Göteborgsmodellen, 2016) to quantify food waste. This means that they collect data according to Fig. 5, with the focus on the food prepared food in the catering unit. The difference from Uppsala schools

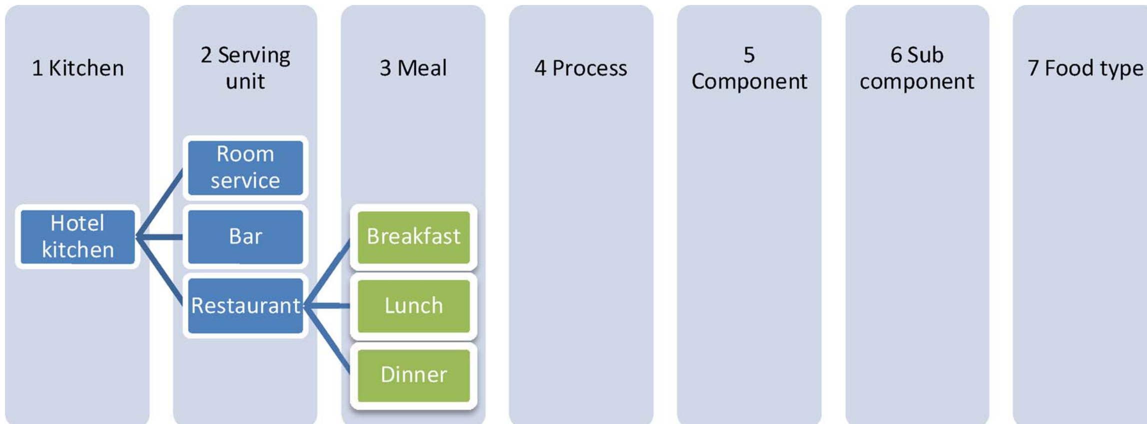

Fig. 8. Hotel in the city of Uppsala, where all waste from the different dining areas is returned to the kitchen, where the mass of the food waste bag is recorded three times per day.

is that Gothenburg pre-schools record the menu, in order to keep track of food served. However, they do not record the number of guests or amount of feed cooked, which means that the results can only be presented in terms of absolute mass.

This case does not differ greatly from the previous case, but highlights the possibility of focusing on specific categories in order to handle waste hotspots. The two observations does not need a framework, but the benefit of the framework is to highlight what is not quantified, in order to see how this quantification overlaps with the previous case. However since only the masses are quantified, it will not be useful to compare waste level for different pre-schools, since they may differ in size and therefore have different amount of waste.

3.1.3. Elderly care home in Sala municipality

Data from food waste quantifications in Sala municipality are presented in Eriksson et al. (2016a, 2016b, 2017a). Here an elderly care unit in Sala was used as an example. The quantification structure of this catering unit was fitted to the tree model in Fig. 6, with both active data points and passive data points included. The catering unit represents a fairly complex structure quantifying food waste on several levels in the framework. In addition to the food waste, it also quantifies the number of guests on the serving unit level (for the restaurant) and for each component/sub-component of the mass of served food is recorded.

This case study is the first in which observations are recorded on different levels in the tree structure. It is of course possible to quantify all these categories without the tree structure, but the framework shows the possibility to aggregate the sub-categories of e.g. serving waste in order to make it comparable with the previous case studies, where this category was quantified only on the process level.

3.1.4. Secondary school in Sala municipality

Another example from Sala municipality is the secondary school Kungsängsgymnasiet, which has data from an extended and temporary quantification period described by Eriksson et al. (2017a). Since this catering unit delivers hot food to two satellite serving units (Lärkbacken primary school and Ängshagen primary school), the quantification data from these two units are included in a simplified way in Fig. 7, even though data sharing on this level does not yet take place. Kungsängsgymnasiet also serves food to pupils from the neighbouring primary school Sörskogen, which is quantified separately. It also quantifies the number of guests in each serving unit and for each component/sub-component the mass of food served is recorded.

This is the most complicated case presented but, since the catering unit belongs to the same organisation as that in the previous case study it shows clear similarities. However, this case highlights the difference between an elderly care unit and a school, since they exclude different amounts by just quantifying lunch food waste. A complicating factor with this case is that the catering unit delivers to two satellite serving units and to two different groups within the school canteen. This challenges the tree structure slightly more, but it also emphasises the need for structuring the data on different hierarchical levels in order to capture all the information provided in the observations conducted. This is of course also a prerequisite for data sharing between the catering units in the future, in order to avoid overproduction of food that cannot be saved for later use in the satellite units.

3.1.5. Hotel 1

A hotel in Uppsala was approached to get a case study outside the public sector. In the hotel, one kitchen supplies three dining areas: a restaurant, a bar and room service. Since all food waste is returned to the kitchen, the sum of all waste is recorded three times per day when the waste is taken out of the kitchen (Fig. 8). The number of guests is recorded in the cashier system, but this information is not used to produce any relative figure of waste per guest. No record is kept of how much food is served and waste is therefore only recorded as mass per meal served.

This hotel case study illustrates a different approach to food waste quantification than in public sector canteens. It might be unnecessary to create a framework for this kind of approach, where the waste bag is simply weighed three times per day. There are similarities between a hotel restaurant and a school canteen, but this example is still difficult to compare with the previous cases, since the bags do not just include the dining room and kitchen waste, but also the waste from the bar and room service.

3.1.6. Hotel 2

One of two hotels described by Peksin (2016) was used as a case (Fig. 9). It reflects the methodology described in Peksin (2016), although this was a very temporary quantification that included three meals where different types of food were quantified for each meal, divided into three different process categories. The mass of waste was related to the number of guests per meal, in order to present a value of waste per portion served.

This hotel has a higher focus on different food types and thus clearly differs from the previous cases, where the focus is on the function in the meal composition of each food type. It is therefore a strength to provide both the meal components and the type of food in the framework, since kitchens and catering units can then be included independent of their focus. However, it is clear that if a hotel kitchen has a buffet-style serving system, it will be more suitable to focus on food types rather than meal components and hotels are therefore likely to simply skip the component and sub-component levels. This could be taken as an indication that the component levels are unnecessary, or should come last in the tree, but we consider it more suitable to have the food type as a sub-category of meal components rather than *vice versa*, since the food types can be divided into many more sub-categories than the meal

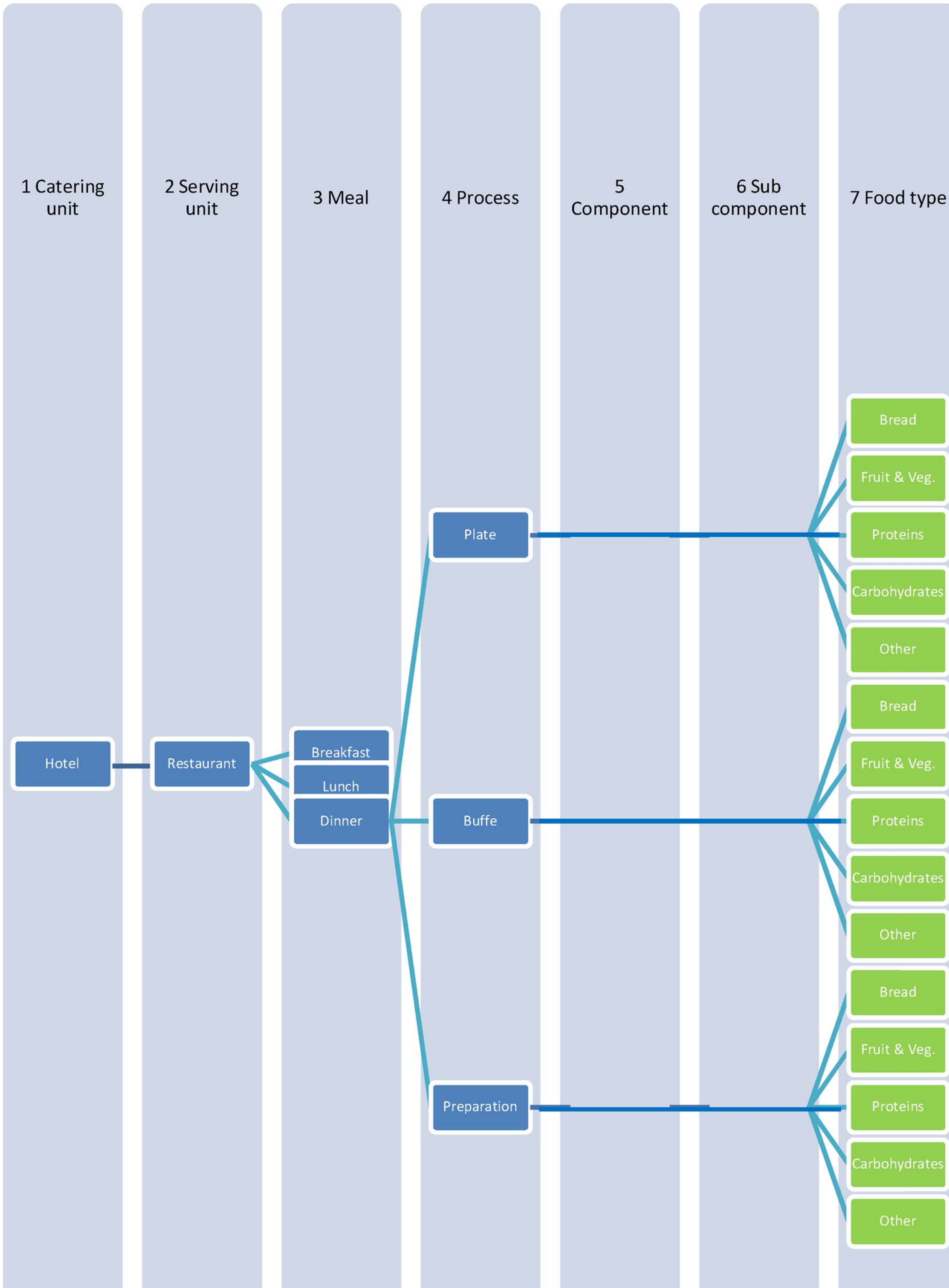

Fig. 9. Hotel 2, where food waste was quantified down to different food types when served in a buffet. For simplicity, only dinner is displayed, but lunch and breakfast were also quantified following the same structure as dinner. Since no inactive waste categories are included in Peksin (2016), only active waste categories are included in the diagram.

components.

3.1.7. Hospital

A medium-sized hospital in southern Sweden was also included as a case (Fig. 10), since a hospital provides yet another type of food service but also since this specific hospital uses a tray system and therefore differs from the other case studies. The quantification included two serving units, since the waste from the food delivered outside the hospital was not quantified. No relative values are calculated, so only the mass numbers for the two categories are included.

However, this system is a quite complex, with many types of special diets delivered to many different care units. Since the care units send back the trays to the hospital kitchen, it would be possible to quantify, on a high level of detail, what is eaten of each type of meal, what part of

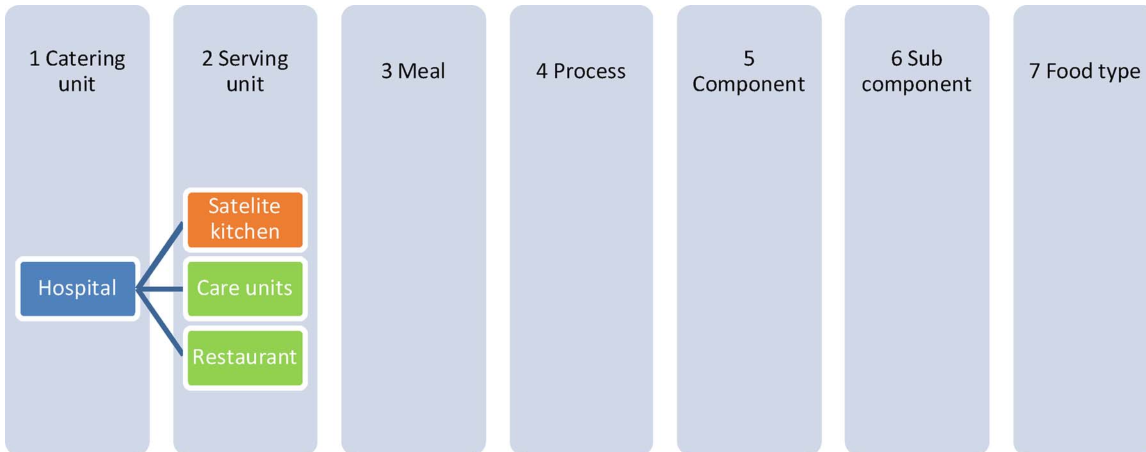

Fig. 10. Medium-sized hospital in southern Sweden, where all waste from two different tray-based serving units is quantified.

each meal is left untouched by the patients, and how many whole trays are sent back to the kitchen untouched. If this were done, the quantification methodology could be divided per meal and per process. The plate waste (or tray waste) would be of particular interest in this instance, since most of the waste is related to the food returned from the care units. In order to design measures, it would be useful to know how much of the waste arises from ordering too many trays and how much arises from patients not finishing their meal or leaving side-orders untouched.

3.2. Overall perspectives on the framework

There is a fundamental difficulty in quantifying food waste in food production (catering) units, the space where raw ingredients are transformed into cooked meals. In contrast, in distribution and retail a food may change article number and price, but does not change other properties like mass. Catering units have much in common with processing industries, where food is also transformed. However, food industries normally produce by-products rather than waste. A catering unit also produces a large variety of meals, based on an even larger variety of ingredients and losses/addition of water. It is therefore difficult to develop a strictly scientific and well-defined methodology for waste quantification that can actually be conducted by kitchen staff.

Based on the different case studies, the proposed framework is flexible enough to include many different methods, but still structured enough to fit all different methodologies. However, food waste quantification is just a starting point for building up a detailed methodology and needs to be supplemented with precise definitions of what exactly to include and what to exclude in different waste categories. This can only be achieved if there is a framework to organise the information. It could also be supplemented with conversion factors in order to make non-comparable data more compatible. This could be done by using data for similar catering units in order to estimate unquantified waste in a particular unit and produce a total value, even though waste has not been quantified. The same logic applies for the quantification period, where shorter quantifications (less than one month a year) can be used to interpolate the waste between quantification periods. The weakness of the framework is that these details have not yet been worked out, and there is therefore too much flexibility for it to qualify as a standardised quantification methodology.

The strength of the suggested framework is the practical approach. One example of this is the possibility to focus the quantification on particular problems, i.e. the quantification can be adjusted over time but still kept within the framework. The level of quantification can be increased by adding data in three different directions. The first direction is time, where additional days are added to the quantification period until the period is continuous. The second direction is depth or resolution, where a specific waste category is divided into sub-categories that are quantified to add resolution. The third direction is to add quantification on the level already quantified, i.e. activating inactive waste categories in order to achieve a result that is closer to the total sum of waste. By using these possibilities, different catering units can quantify food waste at their own desired level, but still obtain data that are comparable to those reported by other, more ambitious units. The only limitation is that they can only compare the parts of the data that overlap, and not completely different categories. Our framework for food waste quantification in food services also allows researchers to compare data from different food waste quantification projects. The tree structure of the framework can best be described as a way of organising and categorising quantitative food waste data from kitchens. Since the tree structure was found to be useful for categorising the food waste data in all selected case studies, we propose it as a foundation on which future food waste quantifications in food services can build.

4. Conclusions

A framework was developed to address the limitations of common food waste quantification methods in food services. The framework was applied to some case studies, where it proved useful in categorising and structuring quantitative food waste data from professional kitchens. There is potential for further development of the framework, to serve as a basis for designing waste quantification procedures in different types of catering units. Together with certain specifications as a minimal basis of quantification, it can serve as a methodological standard.

The advantage of the framework is that it does not just present principles for waste quantification, but goes further to define and describe the important features, specifically for professional catering units. Such units are surprisingly complex in a systems perspective and therefore it is difficult to develop a quantification standard that balances both the strengths of standardisation and flexibility. Our framework makes it possible to have a common base and yet develop individual settings for each catering unit. The tree structure then makes it possible to benchmark different catering units based on overlapping and commonly defined key figures. At the same time, each catering unit can develop its own quantification structure to follow up on specific problems by focusing information collection on the areas with the largest potential to make a difference.

The framework can be applied directly by any catering unit, since many of the paper- or spreadsheet- based quantification systems already in use will fit well to the tree structure. However, its full potential can only be realised when electronic food waste quantification is possible.

Acknowledgments

The study was mainly funded by the organisations that employ the authors, which are the Swedish University of Agricultural Sciences, Uppsala University, Sala Municipality and the consultant company Matomatic AB, but also by the European Union-funded project COnsumers in a SUStainable food supply chain (COSUS). The authors would like to express their gratitude to the employees in the case organisations for providing material and insights for the case studies.

References

Barton, A., Beigg, C., MacDonald, I., Allison, S., 2000. High food wastage and low nutritional intakes in hospital patients. Clin. Nutr. 19, 445–449.
Betz, A., Buchli, J., Göbel, C., Müller, C., 2015. Food waste in the Swiss food service industry –magnitude and potential for reduction. Waste Manage. 35, 218–226.
Brancoli, P., Rousta, K., Bolton, K., 2017. Life cycle assessment of supermarket food waste. Resour. Conserv. Recycl. 118, 39–46.
Byker, C.J., Farris, A.R., Marcenelle, M., Davis, G.C., Serrano, E.L., 2014. Food waste in a school nutrition program after implementation of new lunch program guidelines. J. Nutr. Educ. Behav. 46, 406–411.
Chaboud, G., Daviron, B., 2017. Food losses and waste: navigating the inconsistencies. Global Food Secur. 12, 1–7.
Connors, P.L., Rozell, S.B., 2004. Using a visual plate waste study to monitor menu performance. J. Am. Diet. Assoc. 104, 94–96.
Engström, R., Carlsson-Kanyama, A., 2004. Food losses in food service institutions. Examples from Sweden. Food Policy 29, 203–213.
Eriksson, M., Spångberg, J., 2017. Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. Waste Manage. 60, 786–799.
Eriksson, M., Strid, I., Hansson, P.-A., 2012. Food losses in six Swedish retail stores: wastage of fruit and vegetables in relation to quantities delivered. Conserv. Recycl. 68, 14–20.
Eriksson, M., Strid, I., Hansson, P.-A., 2014. Waste of organic and conventional meat and dairy products—a case study from Swedish retail. Resour. Conserv. Recycl. 83, 44–52.
Eriksson, M., Strid, I., Hansson, P.-A., 2015. Carbon footprint of food waste management options in the waste hierarchy − a Swedish case study. J. Clean. Prod. 93, 115–125.
Eriksson, M., Malefors, C., Björkman, J., Eriksson, E., 2016a. Matsvinn i storkök − en kvantitativ fallstudie av måltidsverksamhet i Sala, Report 091. Department of Energy and Technology, Swedish University of Agricultural Science, Uppsala.
Eriksson, M., Malefors, C., Björkman, J., Eriksson, E., 2016b. Matsvinn i storkök − en analys av riskfaktorer och föreslagna åtgärder, Report 092. Department of Energy and Technology, Swedish University of Agricultural Science, Uppsala.
Eriksson, M., Persson Osowski, C., Malefors, C., Björkman, J., Eriksson, E., 2017a. Quantification of food waste in food canteens − a case study from Sala municipality in Sweden. Waste Manage. 61, 415–422.
Eriksson, M., Ghosh, R., Mattsson, L., Ismatov, A., 2017b. Take back policy in the perspective of food waste generation in the supplier-retailer interface. Recour. Conserv. Recycl. 122, 83–93.
Eriksson, M., 2012. Retail Food Wastage: A Case Study Approach to Quantities and Causes. Department of Energy and Technology, Swedish university of Agricultural Science, Uppsala (Licentiate thesis 045).
Eriksson, M., 2015. Prevention and Management of Supermarket Food Waste: With Focus on Reducing Greenhouse Gas Emissions. Acta Universitatis agriculturae Sueciae, Swedish university of Agricultural Science, Uppsala (Doctoral thesis 2015:119).
FAO, 2011. Global Food Losses and Food Waste. FAO, Rome.
FAO, 2012. The State of Food Insecurity in the World 2012, Economic Growth is Necessary but not Sufficient to Accelerate Reduction of Hunger and Malnutrition. FAO, WFP and IFAD, Rome.
FAO, 2013. Food Wastage Footprint: Impacts on Natural Resources. FAO, Rome.
Göteborgsmodellen, 2016. Göteborgsmodellen för mindre matsvinn. Gothemburg municipality, Gothemburg.
Garnett, T., 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36, S23–S32.
Godfray, C., Reddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science 327, 812–818.
Hackes, B.L., Shanklin, C.W., Taehee, K., Allan, S.Y., 1997. Tray services generates more food waste in dining areas of a continuing-care retirement community. J. Am. Diet. Assoc. 97, 879–882.
Hanks, A.S., Wansink, B., Just, D.R., 2014. Reliability and accuracy of real-time visualization techniques for measuring school cafeteria tray waste: validating the quarter-waste method. J. Acad. Nutr. Dietetics 114, 470–474.
Hayes, J., Kendrick, O.W., 1995. Plate waste and perception of quality of food prepared in conventional vs commissary systems in the Nutrition Program for the Elderly. J. Am. Diet. Assoc. 95.
Jacko, C.C., Dellava, J., Ensle, K., Hoffman, D.J., 2007. Use of the plate waste method to measure food intake in children. J. Ext. 45–46.
Kallbekken, S., Sælen, H., 2013. Nudging hotel guests to reduce food waste as a win–win environmental issue. Econ. Lett. 119, 325–327.
Katajajuuri, J.-M., Silvennoinen, K., Hartikainen, H., Heikkilä, L., Reinikainen, A., 2014. Food waste in the Finnish food chain. J. Clean. Prod. 73, 322–329.
Lebersorger, S., Schneider, F., 2014. Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. Waste Manage. 34, 1911–1919.
Martins, L., Cunha, L., Rodrigues, S., Rocha, A., 2014. Determination of plate waste in primary school lunches by weighing and visual estimation methods: a validation study. Waste Manage. 34, 1362–1368.
Ministry of the Environment and Energy, 2001. Förordning (2001:512) om deponering av avfall. Miljö- och energidepartementet, Stockholm.
Östergren, K., Gustavsson, J., Bos-Brouwers, H., Timmermans, T., Hansen, O.-J., Møller, H., Anderson, G., O'Connor, C., Soethoudt, H., 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. EU FUSIONS.
Papargyropoulou, E., Wright, N., Lozano, R., Steinberger, J., Padfield, R., Ujang, Z., 2016. Conceptual framework for the study of food waste generation and prevention in the hospitality sector. Waste Manage. 49, 326–336.
Peksin, A., 2016. Matsvinn inom hotell – beskrivning av nuläget och identifiering av nyckeltal. The Royal Technical University, Stockholm (Bachelour thesis).
Rutten, M., Nowicki, P., Bogaardt, M.-J., Aramyan, L., 2013. Reducing Food Waste by Households and in Retail in the EU: A Prioritisation Using Economic, Land Use and Food Security Impacts, LEI Report 2013-035. LEI, part of Wageningen UR, The Hague.
SEPA, 2016. Matavfall i Sverige – Uppkomst och behandling 2014, Report 8765. Swedish Environmental Protection Agency, Stockholm.
Scholz, K., Eriksson, M., Strid, I., 2015. Carbon footprint of supermarket food waste. Resour. Conserv. Recycl. 94, 56–65.
School Food Sweden, 2013. SkolmatSveriges kartläggning av skolmåltidens kvalitet läsåret 2012/13. Centrum för epidemiologi och samhällsmedicin, Solna.
Sonnino, R., McWilliam, S., 2011. Food waste, catering practices and public procurement: a case study of hospital food systems in Wales. Food Policy 36, 823–829.
Steen, H., 2017. Exploring Backgrounds for Food Waste in Schools and Kindergartens − Identification and Quantification of Factors Influencing Plate and Serving Waste. Uppsala University, Uppsala (Master thesis).
Steinfeldt, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's Long Shadows: Environmental Issues and Options. Food and Agricultural Organization of the United Nations, Rome.
Stuart, T., 2009. Waste: Uncovering the Global Food Scandal. Penguin Books, London.
Tesco, Tesco and Society report 2014, Available at https://www.tescoplc.com/media/1184/tesco_and_society_review_2014.pdf, Tesco, Cheshunt Hertfordshire.
UN, 2016. United Nations Sustainable Development Goals, Goal 12: Ensure Sustainable Consumption and Production Patterns. United Nations, New York.
World Reasource Institute, 2016. Food Loss and Waste Accounting and Reporting Standard. World Reasource Institute, Washington.