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The "REDUCE" project: definition of a methodology for quantifying food waste by means of targeted waste composition analysis

"REDUCE" (Research, Education, Communication: an integrated approach for food waste prevention) is a biennial project on food waste funded by the Italian Ministry of the Environment and managed by the DISTAL Department at the University of Bologna, with four partners. This paper focuses on a specific research activity related to the definition of a methodology for the quantification of food waste by means of waste composition analysis. This methodology implies the physical separation, weighing, and classification of food waste found in representative samples of municipal waste entering the treatment facilities. The objectives of the research activity, the main steps of the methodology, and some preliminary results are presented in the paper.

1. Introduction

Every year, at the global level, roughly one-third of food suitable for human consumption is unnecessarily wasted or lost, leading to an inefficient use of natural resources, economic costs, and social implications (FAO, 2011; Koivupuro *et al.,* 2012). In the European context (EU-28), the amount of food waste, including the inedible fraction, was estimated equal to 88 million tons in 2012, with around 50% occurring in the household sector (Stenmarck *et al.,* 2016). Due to this massive generation, there is an urgent need to prevent and reduce food waste. The European Commission has set the target to halve the disposal of edible food by 2020 in its Roadmap to a Resource Efficient Europe (European Commission, 2011). In addition, in the revision of the European Waste Framework Directive 2008/98/EC (European Commission, 2015), Member States are required to establish prevention measures specifically related to food waste, in line with the goal 12.3 of the 2030 Agenda for Sustainable Development adopted by the United Nations (by 2030, halve per capita global food waste at the retail and consumer levels).

According to this framework, the Italian Ministry of the Environment has recently funded "REDUCE", a biennial project of Research, Education, and

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Communication on food waste managed by the Department DISTAL at the University of Bologna with the collaboration of four research partners. Among its specific objectives, the project aims at improving the knowledge related to the amount, composition, and causes of food waste at the household level. In the existing literature, different methodological approaches have been used to quantify and classify the domestic food waste. These approaches can be divided into three main categories: measuring and reporting by the consumer (questionnaires, interviews, and kitchen diaries), food waste composition analysis, and estimates from statistical data. Each methodology shows advantages and disadvantages (Tab. 1) and for this reason a combination of the three methods is recommended (Koivupuro *et al.,* 2012; Jörissen *et al.,* 2015).

This paper focuses on the methodology of waste composition analysis, used to physically separate, weigh and categorize the food waste. In the recent literature on the topic, a number of authors have applied this methodology in different European countries by analyzing the content of waste bins of a number of representative households. All these authors found large potentials for food waste minimization among the European households, since the avoidable fraction ranges from 35% to 60% by weight of the overall food waste and it is mainly composed of perishable products (Tab. 2).

2. Objectives of the research activity

This paper is related to the specific research activity consisting in the definition of a standard methodology for the quantification of food waste by means of waste composition analysis at the treatment facilities. This methodology is based on physical separation, weighing, and classification of food waste contained in two municipal waste fractions: the residual waste and the organic waste from separated collection. The ultimate goal of the research is to incorporate the methodology into the periodical waste analyses carried out by local authorities and environmental protection agencies, in order to provide historical series of data specifically related to food waste at the national level. Food waste statistics may contribute to raise awareness among citizens as well as to support the definition and the monitoring of specific prevention measures.

The following sections of the paper are dedicated to the description of the methodology with specific reference to the municipal residual waste. The methodology for the residual waste was defined in cooperation with Conai (the Italian National Consortium for Packaging waste), which performs periodical analyses on the waste delivered to incineration plants.

Tab. 1. Main methodological approaches for the quantification and classification of food waste at the household level: definition, advantages and disadvantages (Lebersorger and Schneider, 2011; Koivupuro *et al.*, 2012; Møller *et al.*, 2014; Jörissen *et al.*, 2015; World Resources Institute, 2016)

Methodological approach	Definition	Advantages	Disadvantages
Interviews and questionnaires	Gathering of information on food waste (attitudes, beliefs, and behaviours) from a large number of individuals through a set of structured questions	- Methodically simple approach to collect qualitative information about food waste	- Possible will of the respondents to present themselves in a positive light (respondents tend to underestimate their losses when self-reporting or they tend to give "socially accepted answers")
Kitchen diaries	Participants measure their own food waste and record its quantity and other information (type, reason of disposal) on a regular basis	- Collection of detailed data about the composition and the reason of each single disposal - The influence of socio-demographical, behavioural and attitudinal factors can be investigated	- Possible underestimation of food waste due to: 1. participants may forget to record or decide not to record part of food waste due to the significant effort required by the activity 2. changes in the handling of foodstuff during the test
Waste composition analysis	Physical separation, weighing, and classification of food waste from representative samples of municipal waste. The analysis is performed by a third party	- More objective and accurate analysis compared to consumer self-measurement methods - Possibility to apply the methodology to the traditional analyses of the municipal waste	- Lack of a standard methodology and inconsistency in the definitions reported in the existing literature - High degradation of the waste that can affect the separation and the identification of single items - No information about the reasons behind the disposal - Poor representativeness of the analysed sample
Estimates from statistical data	- Estimate based on the difference between the supply of food and what was eaten (nutrition data) for a specific geographical area - Estimate from municipal waste statistics	No involvement of consumers	Estimates may be prone to uncertainties mainly due to the used assumptions and models

Tab. 2. Structure of food waste in different European countries acquired through household waste composition analysis (literature review)

Source	Country	Type of analysed municipal waste	Food waste	Avoidable food waste	Composition of the avoidable food waste
Edjabou M.E. et al. (2016)	Denmark (1474 households)	Residual Waste [1]	85 kg/inhabitant/year	*56%* of food waste	Mainly vegetable products (*71%*) [2]
Lebersorger S. and Schneider F. (2011)	Austria (137 sample units)	Residual Waste	33 kg/inhabitant/year	*56%* of food waste	Mainly vegetables (*18%*), bread (*15%*), confectionery/desserts (12%), meat (11%)
Schott A.B.S. et al. (2013)	Sweden (2590 households)	Residual waste and separately-collected food waste	175 kg/household/year	*34%* of food waste	Not reported
Ventour L. (2008)	United Kingdom (2138 households)	Residual waste and separately-collected food waste	96 kg/inhabitant/year	*61%* of food waste	Potatoes, slices of bread and apples resulted the most wasted products

[1] In the studied area, food waste was neither source-segregated nor accepted at recycling stations.
[2] Vegetable products include non-animal derived food like fresh vegetables and salads, fruit, bakery, drinks and confectionery, canned food.

3. Materials and methods

The development of the methodology has included:

- the assumption of a reference definition for food waste;
- the evaluation of possible classifications of food waste into subcategories;
- the definition of a standard procedure for the analysis at waste treatment facilities in cooperation with Conai.

3.1 Food waste definition

In this study, the definition of food waste proposed in the context of the European Project "FUSIONS" was considered (Östergren *et al.,* 2014). According to this definition, food waste includes all food products and beverages intended for human consumption and discarded, with the associated inedible elements. Pet food, medicines, cigarettes, and food packaging are thus excluded.

3.2 Possible classifications of food waste

The defined methodology also includes a classification of food waste into subcategories. According to the FUSIONS Project guidelines, which recommend including the inedible elements in the estimation, food waste is classified into three main categories (Quested and Johnson, 2009):

- *avoidable food waste*, composed of edible material, at some point prior to disposal, which was discarded regardless of the reason (the category includes edible, stale, mouldy or out-of-date food products and beverages);
- *possibly avoidable food waste*, composed of edible parts of food, which some people eat and others not (e.g., apple skin), or that can be eaten when prepared in one way but not in another (e.g., potato skins);
- *unavoidable food waste*, i.e. parts of food which are inedible under normal circumstances (for example meat bones, used tea bags, and apple cores).

In order not to leave room for subjective interpretations, each element is classified among the three categories according to the characteristics of edibility defined in the context of the FUSIONS Project (Tostivint *et al.,* 2016). This source provides a complete list of edible, technically edible, and inedible parts of food (Tab. 3). Whole products including different components (for example a banana composed by the flesh intended for human consumption and by the inedible peel) are considered avoidable in this methodology, following the

Tab. 3. Examples of edible, technically edible, and inedible parts of food for some fruit and vegetable products. The complete list is available in Tostivint *et al*. (2016)

Product	Classification		
	Edible	Technically edible	Inedible
Apple	Flesh	Skin	Core/stem
Orange and other citrus fruits	Flesh	Skin	Stem
Stone fruits	Flesh	Plum and peach peel	Stone/mango and avocado skin
Banana	Flesh	-	Skin
Carrot/cucumber/courgette	Flesh	Peel	Top/end/stalks
Onion	Flesh	-	Sprouts/peel
Peas	Peas	-	Pea pods

example of other studies related to food waste analysis (Quested and Johnson, 2009; Edjabou *et al.,* 2016).

After this first classification, a further characterisation of avoidable food waste is proposed in order to collect more indications about its composition and thus to support the definition of specific prevention measures. In particular, two classifications of the avoidable waste were selected for the methodology:

- a classification by product type (for example, fruit and vegetable products, dairy products, meat, and fish);
- a classification based on packaging: food waste inside an unopened sale packaging, food waste inside an opened sale packaging, and loose food waste (Schott *et al.,* 2013).

The state of waste degradation and the lack of information about the reasons behind the disposal prevented the application of other classifications, like that by life cycle stage proposed by Salhofer S. *et al.* in the year 2008 (food in its original condition, only partially consumed food, residues in course of food preparation, and leftovers from plates).

3.3 Definition of a standard procedure for the analysis at waste treatment facilities

Every year, Conai performs composition analyses of the residual waste delivered to Italian incineration plants. The objective is to evaluate the amount of packaging waste made of aluminium, paper, plastic, and wood sent to ener-

gy recovery as required by the Directive 2004/12/EC on packaging and packaging waste (European Parliament and Council, 2004).

The first step of the Conai analysis consists in the preparation of a sample representative of the residual waste processed by the plant (about 150-200 kg). The sample is directly taken from the storage pit where the waste is mixed before the combustion or, alternatively, it is composed with garbage bags associated to different catchment areas and unloaded from collection vehicles entering the plant. The sample is then manually sorted into 16 main waste categories (including the organic fraction) and the percentage by weight of each category is calculated. For each incineration plant, the described procedure is repeated three times in the same day (ANPA, 2000).

Starting from such standard procedure, a further detailed analysis on food waste (a subcategory of the organic fraction) was defined for the research activity of the REDUCE Project. The FUSIONS food waste quantification manual (Tostivint *et al.,* 2016), the Food Loss and Waste Accounting and Reporting Protocol of the World Resources Institute (2016), and the paper by Lebersorger and Schneider (2011) served as a reference during the design of the analysis.

The analytical procedure includes the following steps:

- weighing of the overall food waste;
- separation of each identifiable element from the sample of food waste;
- weighing of each identified element with a scale of 1 gram of accuracy and note of the relevant information for the classification: product type (e.g. a slice of bread, bones, banana peel), weight, and other characteristics (Tab. 4). For packaged products, a standard process of identification was defined. First, the current level of filling is noted (unopened packaging with the whole product inside or opened packaging with food partially consumed inside). Then, the packaging is removed and weighed separately from the contained food. If the separation is not feasible (e.g. the removal of the jam from a jar), an estimate of the packaging weight is derived from the net weight imprinted on the pack (only for unopened items), from the mass of an identical empty packaging or, in the absence of these alternatives, from a visual estimate of the food waste amount;
- weighing of the unclassifiable remaining fraction, i.e. elements of food waste whose level of degradation makes them inseparable and not further classifiable.

The described procedure can be applied each time the delivered waste comes directly from the collection, without intermediate pre-treatment. In fact, the pre-treatment of the residual waste, which might take place before the waste is delivered to the final treatment plant, implies some disadvantages for the analysis on food waste. First of all, the material is typically shredded, making the identification of the single items very difficult. Moreover, when a bio-

Tab. 4. Example of table used for the characterisation of elements of food waste

Identified element	Inside sale packaging?	Other characteristics	Product weight (g)	Packaging weight (g)
Apple	no	Whole	200	-
Meat	no	Some raw steaks	300	-
Banana peel	no	-	900	-
Bones	no	-	400	-
Pasta	yes (unopened)	1 kg bag	1000	10
Water	yes (opened)	Bottle of 0.5 L	240	15

logical stage is included during pre-treatment, the organic fraction is inevitably affected by moisture reduction and degradation of the biodegradable carbon.

A first campaign of analysis on the residual waste was performed during the spring of year 2016 (Tab. 5). The residual waste delivered to eight incineration plants was selected based on the following criteria:

- considering different Italian regions (Emilia-Romagna, Lombardy, and Piedmont) in order to take into account the geographical variability of the waste composition;
- locations where previous analyses of Conai showed a non-negligible amount of food waste in the residual waste (higher than 10% by weight);
- high catchment basin, in terms of generated waste.

At each site, Conai performed 3 traditional analyses on the residual waste (24 analyses in total). 14 out of 24 samples were then subjected to a further composition analysis of food waste.

4. Preliminary results and discussion

For the analysed waste samples, in the year 2016, 15% by weight of the residual waste was classified as food waste on the average (Tab. 6). Compared to the previous year, a 4% reduction by weight was observed, as a result of the continuous increase of the separated collection of the organic waste in Italy during the recent years (from 13% of the total municipal waste in 2010 to 21% in 2015; ISPRA 2013 and ISPRA 2016).

As regards the composition of food waste, the first aspect is related to the unclassifiable fraction, whose contribution by weight ranged from 29% to 74% of the sample of food waste (48% on the average), confirming that the degradation of the waste really limits the analysis (Fig. 1). Packaged food waste or

Tab. 5. Main characteristics of the incineration plants where the residual waste was sampled. The amount of treated waste is related to the year 2015 and it is reported in ISPRA (2016) while the average percentage of food waste in the residual waste was provided by Conai for the year 2015

Incineration plant	Treated waste (t/year)	Food waste (% by weight)	Date of analysis	Number of composition analysis on food waste
A	126,643	*11%*	26/04/2016	1
B	61,644	*15%*	27/04/2016	2
C	113,162	*30%*	28/04/2016	3
D	151,555	*16%*	5/05/2016	2
E	213,821	*20%*	27/05/2016	1
F	472,754	*27%*	22/06/2016	2
G	505,680	*15%*	29/06/2016	2
H	686,575	*21%*	30/06/2016	1

Tab. 6. Amount of food waste (percentage by weight) in the three samples of residual waste analysed at each incineration plant, with the corresponding average value for the year 2016. The average amount of food waste related to the year 2015 in the same plants is also reported for comparison purpose. Note: samples in grey were subjected to a further composition analysis of the food waste

Incineration plant	Sample 1 (2016)	Sample 2 (2016)	Sample 3 (2016)	Average (2016)	Average (2015)
A	*9%*	*7%*	*8%*	*8%*	*11%*
B	*13%*	*13%*	*13%*	*13%*	*15%*
C	*9%*	*12%*	*6%*	*9%*	*30%*
D	*22%*	*13%*	*11%*	*15%*	*16%*
E	*12%*	*11%*	*8%*	*10%*	*20%*
F	*13%*	*30%*	*20%*	*21%*	*27%*
G	*22%*	*19%*	*23%*	*21%*	*15%*
H	*30%*	*24%*	*9%*	*21%*	*21%*
Average amount of food waste for the eight incinerators (24 analyses)				*15%*	*19%*

whole loose items (for example an apple or a whole loaf) were typically identified, while food preparation residues or leftovers from plates could not always be separated and classified precisely. Most important factors responsible for the presence of the unclassifiable fraction include: the biological degradation happening between the disposal of the waste and its sorting (the organic waste is highly putrescible compared to other waste fractions) and the process of mixing and compaction of the waste in the collection vehicles and in the storage pit of the plant (where the material is mixed with buckets).

Despite such limitations, interesting data were collected about the characteristics of food waste. The avoidable fraction represented 28% of the total food waste on the average (Fig. 1). This value is lower if compared to other European studies (which found from 35% to 60% of the overall food waste), but it is a preliminary indication only related to the residual waste. In terms of product composition, the avoidable category resulted mainly composed of perishable food items (fruit, vegetables, and bread, above all; Fig. 2), while the classification based on packaging showed that more than 10% by weight of the avoidable products was discarded still in its unopened packaging in 6 out of 14 analyses (Fig. 3). In relation to this aspect, a similar indication was reported by Lebersorger *et al.* (2011) for the residual waste in the Austrian context (11% by mass of the avoidable food waste was classified as unused and originally packaged).

Fig. 1. Classification of food waste into different categories: avoidable food waste, possibly avoidable food waste, unavoidable food waste, extraneous fraction (packaging separated from food during the identification, pet food, medicines, and contaminations from other waste categories) and unclassifiable remaining fraction. * S stands for SAMPLE

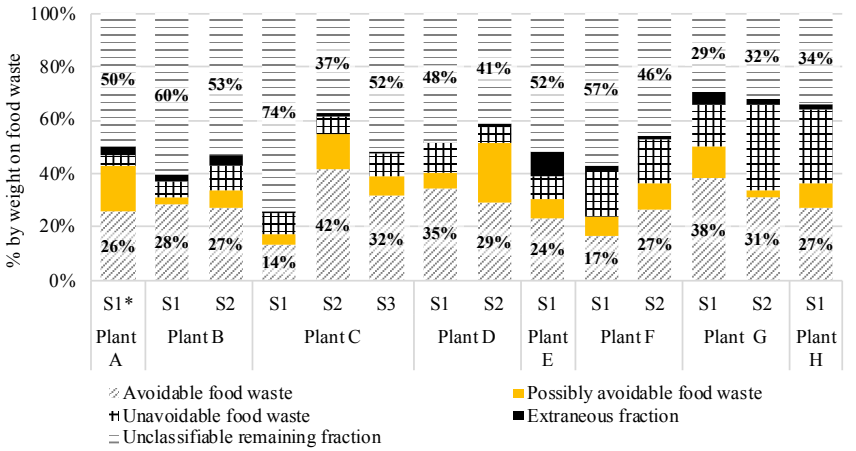


Fig. 2. Classification of the avoidable food waste by product type

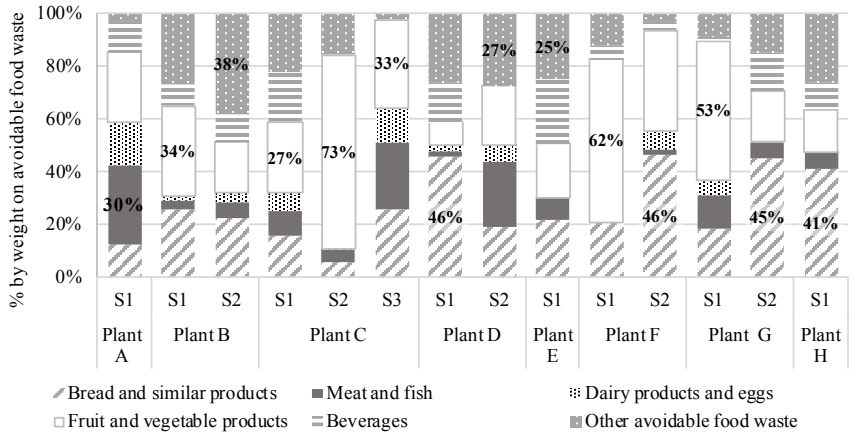
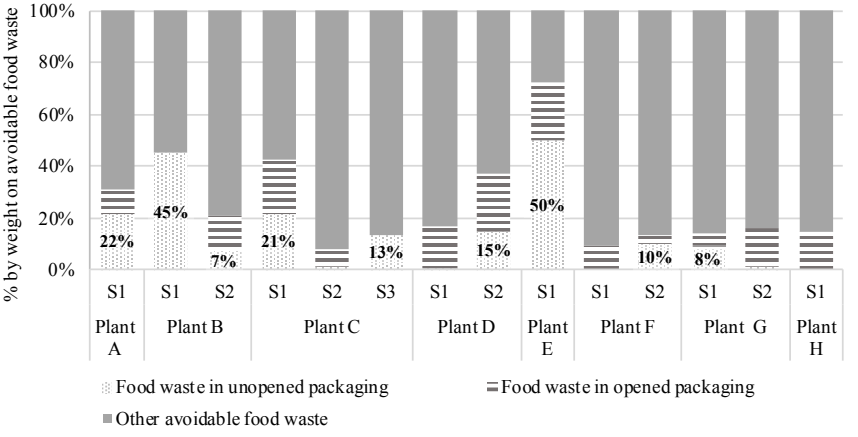


Fig. 3. Classification of the avoidable food waste into: food waste in its unopened sale packaging, food waste in its opened sale packaging, and other avoidable food waste



Possibly avoidable and unavoidable food waste revealed a lower average percentage by weight (9% and 13% of the total food waste, respectively). However, the unavoidable food waste showed a clear seasonal variability, with a higher contribution (more than 15%) for the last five samples (Fig. 1), which were analysed during the early summer, with a significant presence of watermelon rinds.

5. Conclusions and future steps of the research

The minimisation and prevention of food waste require a good understanding of its amount and composition. The defined methodology, if integrated within the routine waste composition analysis performed by the environmental protection agencies in Italy, can be a valid tool for monitoring the characteristics of food waste at national/regional level, at regular intervals (on an annual or biennial basis), and at an affordable cost. In relation to this last aspect, the additional charges to a traditional waste analysis are mainly related to the increase of the personnel due to the more time-consuming procedure.

The following step of the research activity will be focused on the organic waste from separated collection, where the authors expect to find appreciable amounts of avoidable food waste.

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References

Agenzia Nazionale per la Protezione dell'Ambiente - ANPA (2000). Analisi merceologica dei rifiuti urbani: rassegna di metodologie e definizione di una metodica di riferimento. ANPA, Dipartimento Stato dell'Ambiente, Controlli e Sistemi Informativi, Roma, Italia. Available at: https://www.arpal.gov.it/files/rifiuti/ANPA_Merceologia.pdf

Consorzio Nazionale Imballaggi - Conai (2016). Personal communication

Edjabou M.E., Petersen C., Scheutz C. and Astrup T.F. (2016). Food waste from Danish households: Generation and composition. *Waste Management*, 52: 256-268. DOI: 10.1016/j.wasman.2016.03.032

European Commission (2011). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe. COM (2011) 571 final, Brussels, 20.09.2011.

European Commission (2015). Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste. COM (2015) 595 final, Brussels, 2.12.2015.

European Parliament and Council of the European Union (2004). Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste. *Official Journal of the European Union L* 47: 26-31, 18.02.2004.

Food and Agriculture Organization of the United Nations - FAO (2011). Global food losses and food waste - Extent, causes and prevention. Rome, Italy. ISBN 978-92-5-107205-9. Available at: http://www.fao.org/docrep/014/mb060e/mb060e.pdf

Istituto Superiore per la Protezione e la Ricerca Ambientale - ISPRA (2013). Rapporto Rifiuti Urbani - Edizione 2013. Available at: http://www.isprambiente.gov.it/it/ pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione-2013

ISPRA (2016). Rapporto Rifiuti Urbani - Edizione 2016. Available at: http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione-2016

Jörissen J., Priefer C. and 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. DOI: 10.3390/su7032695

Koivupuro H.K., Hartikainen H., Silvennoinen K., Katajajuuri J.M., Heikintalo N., Reinikainen A. and Jalkanen L. (2012). Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. *International Journal of Consumer Studies*, 36(2): 183-191. DOI: 10.1111/j.1470-6431.2011.01080.x

Lebersorger S. and Schneider F. (2011). Discussion on the methodology for determining food waste in household waste composition studies. *Waste Management*, 31(9-10): 1924-1933. DOI: 10.1016/j.wasman.2011.05.023

Møller H., Hanssen O.J., Gustavsson J., Östergren K., Stenmarck Å. and Dekhtyar P. (2014). Report on review of (food) waste reporting methodology and practice. FUSIONS EU Project. Available at: https://www.eu-fusions.org/index.php/publications

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. and Redlingshöfer B. (2014). FUSIONS Definitional Framework for Food Waste. FUSIONS EU Project. Available at: https://www.eu-fusions.org/index.php/publications

Quested T. and Johnson H. (2009). Household food and drink waste in the UK. Final report prepared by WRAP (The Waste & Resources Action Programme), Banbury (UK), ISBN:1-84405-430-6.

Salhofer S., Obersteiner G., Schneider F. and Lebersorger S. (2008). Potentials for the prevention of municipal solid waste. *Waste Management* 28(2): 245-259. DOI:10.1016/j.wasman.2007.02.026

Schott A.B.S., Vukicevic S., Bohn I. and Andersson T. (2013). Potentials for food waste minimization and effects on potential biogas production through anaerobic digestion. *Waste Management & Research* 31(8): 811-819. DOI: 10.1177/0734242X13487584

Stenmarck Å., Jensen C., Quested T. and Moates G. (2016). Estimates of European food waste levels. FUSIONS EU Project. Available at: https://www.eu-fusions.org/index.php/publications

Tostivint C., Östergren K., Quested T., Soethoudt H., Stenmarck Å., Svanes E. and O'Connor C. (2016). Food waste quantification manual to monitor food waste amounts and progression. FUSIONS EU Project. Available at: https://www.eu-fusions.org/index.php/publications

United Nations (2015). Resolution adopted by the General Assembly on 25 September 2015 - Transforming our world: the 2030 Agenda for Sustainable Development. UN General Assembly Resolution 70/1. Available at: http://www.un.org/en/ga/70/resolutions.shtml

Ventour L. (2008). The food we waste. Project code: RBC405-0010, report prepared for WRAP (The Waste & Resources Action Programme).

World Resources Institute (2016). Food Loss and Waste Accounting and Reporting Standard. Version 1.0. Available at: http://www.wri.org/our-work/project/food-loss-waste-protocol