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Discussion on the methodology for determining food waste in household waste composition studies

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ABSTRACT

Food waste has become an increasingly discussed topic in recent years. However, there is little authoritative data on food waste quantities and composition and systematic and comparable data are missing. Household waste composition analyses, which are often carried out routinely at regular or irregular intervals, provide an opportunity for obtaining data about food waste at both local and regional levels. The results of prior waste composition studies are not really comparable due to the different classifications, definitions and methods used; in addition, these are mostly insufficiently described and not reproducible by a third party. The aim of this paper is to discuss a methodology for determining the proportion of food waste in household waste composition studies, by analysing specific problems and possible solutions. For that purpose, findings from the literature are analysed and the approach and results of a composition analysis of residual waste of a stratified sample (urban, rural area) are presented. The study suggests that in order to avoid a significant loss of information, waste should not be sieved before sorting and packed food waste should be classified into the relevant food waste category together with its packaging. The case study showed that the overall influence of the proportion of food packaging included in the food waste category, which amounted to only 8%, did not significantly influence the results and can therefore be disregarded.

1. Introduction

Household food waste has become an increasingly discussed topic in recent years because waste composition studies have indicated significant quantities of food waste are generated and consequently, there is significant potential for waste prevention (e.g. Lebersorger and Salhofer, 2003; Salhofer et al., 2008; WRAP, 2008; Monier et al., 2010). The increasing importance of this topic has been underlined by a number of recent studies (e.g. Schneider and Obersteiner, 2007; WRAP, 2008, 2009a,b; Langley et al., 2010; Parfitt et al., 2010; Monier et al., 2010), pilot projects (e.g. Schneider and Lebersorger, 2009) and campaigns such as the "Love Food Hate Waste" campaign launched in Great Britain in November 2007 (WRAP, 2008) or the campaign "Less food wasted means more money in your wallet" in the Helsinki Metropolitan area from 2005 to 2007 (YTV, 2008). Food waste has also been defined as one of the main topics in the Austrian waste prevention program which is currently reviewed and will be published in the context of the Waste Management Plan in 2011. More and more national and local authorities have realized the problem of food waste and request data on regional level and strategies for prevention (cf. Monier et al., 2010).

However, authoritative data on food waste quantities and composition are fragmentary (Parfitt et al., 2010; Langley et al., 2010; Monier et al., 2010) and systematic and comparable data are missing. An international literature review and interviews with international experts by Parfitt et al. (2010) with the aim of quantifying food waste in the global food supply chain revealed significant information gaps and uncertainties. Parfitt et al. (2010) found that the greatest potential for the reduction of food waste in the developed world lay with retailers, food services and consumers. Studies focussing on household or post-consumer level have been made for different regional levels: nation (e.g. WRAP, 2008, 2009b for the UK; Watanabe, 2009 for Japan), region (e.g. Schneider and Obersteiner, 2007 in 2 Austrian provinces; Fehr and Romão, 2001 in a Brazilian city; Pekcan et al., 2006 in Ankara, Turkey) and pilot areas/samples (e.g. Langley et al., 2010 in 33 households in UK; Schneider and Lebersorger, 2009 in 14 multi-family dwellings in Austria, Selzer et al., 2009 in 51 households in Austria; Van Garde and Woodburn, 1987 in 243 households in Oregon, U.S.). A variety of methods have been used, such as waste composition analyses (e.g. WRAP, 2008; Watanabe, 2009; Schneider and Obersteiner, 2007; Fehr and Romão, 2001), kitchen diaries (e.g. WRAP, 2008; Selzer et al., 2009; Langley et al., 2010; Wenlock

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et al., 1980), estimations from statistical data on food supply and nutrition (e.g. Watanabe, 2009; Hall et al., 2009; Kantor et al., 1997), or questionnaire surveys [quantitative standardized interviews (Schneider and Lebersorger, 2009; Pekcan et al., 2006) or qualitative interviews (Glanz and Schneider, 2009)]. The most extensive studies were published by WRAP (2009a,b, 2008), which investigated household food and drink waste in the UK disposed via kerbside collection of residual waste, food waste collections, household waste recycling centres, sewers and home composting or fed to animals. The methodology used comprised waste composition analyses, kitchen diaries and a review of existing waste data. However, these approaches are generally costly and cannot be directly used as standard methodology for obtaining data on a local level.

An obvious option to determine the proportion of food waste is to conduct a household waste composition analysis. Compared to consumer self-measurement methods such as kitchen diaries or questionnaire surveys, which represent the participants' subjective point of view and require significant effort from the participants, waste composition studies can be carried out by a third party and are more objective and accurate (cf. Langley et al., 2010). Furthermore, as household waste composition analyses are often carried out routinely at regular or irregular intervals, the determination of food waste as separate waste fraction suggests itself and has been increasingly demanded by local authorities in recent years, for example by the Austrian provincial governments of Lower Austria (Obersteiner and Schneider, 2006), Salzburg (Lebersorger and Salhofer, 2007), Styria (TBU, 2009) or the Tyrol (Technisches Büro Hauer, 2010). The problem with such studies is that there is no international standard methodology and no consistency in the definitions used. A variety of individual approaches have been used, e.g. sorting with/without prior sieving, different classifications, sampling from waste containers or collection vehicle, and different consideration of food packaging. Moreover, descriptions of the methodology often lack substantial information, particularly concerning the definition of food waste categories, the exact classification of individual food items and the consideration of food packaging, so that the methodology and results are not reproducible by a third party. Therefore, data are neither comparable among different regions (cross-sectional analysis) nor between different point of times (longitudinal analysis). In order to obtain reliable data for, e.g. planning and evaluating the effect of prevention measures, reliable, authoritative and comparable data are required.

This paper discusses methodological aspects which have to be considered in household waste composition studies with focus upon food waste. The aim of the paper is to provide a basis for the development of an international standard methodology. The paper intends to foster the discussion within the scientific community especially regarding food waste due to the increasing research activities on this topic in recent years. In detail the following research questions are investigated:

- Which specific problems are associated with the analysis of food waste in household waste composition studies?
- Which possible solutions are there?
- How should packaged food waste components be handled and how significant is the influence of food packaging included in the food waste category?

On the basis of a literature review, specific problems are discussed at first. Results from a case study – a composition analysis of residual waste from households in a selected region – are used to illustrate the approach, to identify possible stratification criteria and to quantify the influence of food packaging.

2. Specific problems regarding food waste in waste composition analyses

There is not yet an agreed international standard method for conducting household waste composition studies (Dahlen and Lagerkvist, 2008) despite attempts to propose a European standard characterization method for municipal solid waste (European Commission, 2004). From a review of methods for household waste composition studies, Dahlen and Lagerkvist (2008) identified key factors as: the number and types of strata; the sample size; the choice of the sampling location; and the type and number of waste component categories. The determination of food waste involves additional and specific problems which are discussed below.

2.1. Classification of food waste

The simplest categorization of biowaste from households which has been used by most waste composition analyses is the differentiation into garden waste and food waste (e.g. DEFRA, 2010; Williams and Kelly, 2003), respectively kitchen waste (European Commission, 2004; Lebersorger and Salhofer, 2003). However, though the categories literally are the same, the classification of individual waste components may vary (cf. Dahlen and Lagerkvist, 2008).

As regards the further classification of food waste into subcategories, practically every study uses its own subcategories. Most studies have in common that they basically differentiate avoidable and non-avoidable food waste, but the definitions are not consistent. While for example Langley et al. (2010) and Schneider and Obersteiner (2007) consider all preparation by-products and residues of food preparation inedible and therefore non-avoidable, WRAP (2009a) uses an additional subcategory of "possibly avoidable food" (see Table 1). Possibly avoidable food is considered edible and defined by WRAP (2009a) as "food and drink 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)". As for avoidable food, studies generally agree that whole unused and part consumed food would be avoidable (WRAP, 2009a; Schneider and Obersteiner, 2007; Langley et al., 2010), but differ in the classification of post-preparation and consumption residues. A further possibility with regard to waste treatment, is the classification of food waste into possibly recyclable, i.e. suitable for home composting or biowaste collection, and non-recyclable food waste (Lebersorger and Salhofer, 2003; TBU, 2009). However, this classification is circumstantial and does not deliver comparable results, since the definition which components are recyclable depends among others on the local collection system. For instance, in some regions meat and bones are intended for separate biowaste collection, in other regions not.

Tertiary subcategories classify food into different categories by life cycle stage [e.g. composite gunge, preparation by-products, post-preparation, part consumed, whole unused (Langley et al., 2010) or food preparation residues, leftovers, original food, partly used food products (Schneider and Obersteiner, 2007)], by preparation state [e.g. fresh, ready to consume, cooked or prepared at home, tinned, etc. (WRAP, 2008)] or by food category [e.g. fruit, vegetables, drinks, bakery, meat and fish, etc. (WRAP, 2009a)].

The exact classification of individual food waste components in the sorting process is often ambiguous and requires a very detailed, elaborated sorting catalogue, particularly for subcategories. For example, difficulties include:

- The classification of food consisting of different ingredients (e.g. a cooked dish with meat and vegetables) to product category.

Table 1
Classifications of food waste into subcategories used by different studies.

Subcategory	Langley et al. (2010)	Schneider and Obersteiner (2007)	WRAP (2009a)
Preparation residues	Non-avoidable	Non-avoidable	Non-avoidable or possibly avoidable
Post-preparation and consumption residues	Avoidable	Partly avoidable	Avoidable or possibly avoidable[a]
Part consumed food (not whole as purchased)	Avoidable	Avoidable	Avoidable
Whole unused food (as purchased, whole, unopened)	Avoidable	Avoidable	Avoidable

[a] Post-preparation and consumption residues are not differentiated as separate category. From the definitions by WRAP (2009a) it can be concluded that these residues can be found both in the category "avoidable food" and "possibly avoidable food".

- Of whole unused food without packaging (e.g. a cucumber, one apple, one onion) where it can only be guessed whether it has been part of a larger package (category part consumed, not whole as purchased) or whether it has been purchased as single item (whole unused, as purchased).
- Or food in a condition or state of degradation which makes identification difficult or impossible (see Section 2.2).

Dahlen and Lagerkvist (2008) generally recommend that any kind of secondary categories can be chosen, as long as they can be unmistakably subsumed to the correct primary categories. In order to obtain comparable and more detailed information about the composition of food waste, it is necessary to stringently define a limited number of standard secondary categories.

For the case study which is presented in this paper, a classification scheme of food waste was developed with the intention to minimize the scope for subjective interpretation. The definitions (Section 3.3) and results (Sections 4.1 and 4.3) are presented.

2.2. State of degradation

The state of degradation of food items because of physical, chemical and biological factors (including microbial degradation, infestation by flies, feeding by vermin and pets, type of storage container and its location) affects a researcher's ability to unambiguously and reproducibly identify, separate and classify this material, as well as the mass of each item (Langley et al., 2010). Influencing factors include: the time between the disposal of a food item into the waste bin and its sorting; temperature (season); and the degree of compaction and commingling which on the other hand also relates to the sampling location (e.g. waste bin at the household level, waste collection vehicle) (Dahlen and Lagerkvist, 2008; Langley et al., 2010).

Food waste composition studies (e.g. Schneider and Obersteiner, 2007; WRAP, 2009a) provide hardly any information about time aspects, such as age of the analysed waste or time difference between sampling and sorting day. Sampling at the household level is generally recommended by the European Commission (2004), and by Dahlen and Lagerkvist (2008) for analyses of differences and distribution in households' behaviour and with regard to the state of food degradation. Identifying individual waste components from a sample taken from a collection vehicle is more difficult and inaccurate, because the process of mixing and compaction in the collection vehicle decreases particle-size and increases contamination of individual waste components (Dahlen and Lagerkvist, 2008; European Commission, 2004). In general, Dahlen and Lagerkvist (2008) recommend that each sample should be sorted within 2 days from the sampling day. However, this time limit conflicts with practical conditions, when for example samples from a couple of municipalities with different dates and intervals of waste collection shall be analysed centrally on consecutive days. Considering that the age of waste in the collection container before sampling may vary from less than 1–42 days, depending on the intervals of municipal waste collection (ranging from several times a day to every 6 weeks) and on the moment when it was actually discarded, a violation of the 2 days time limit seems tolerable. Nonetheless, it should be tried to keep the intervals between waste generation, sampling and sorting as short as possible.

2.3. Consideration of food packaging

A specific problem is the consideration of food packaging. In the sorting process of waste composition analyses, food waste components are usually separated out in their packaging. On the one hand, the packaging encloses loose goods and provides important additional information about the life cycle stage of the food (e.g. whole unopened package, part consumed), best-before or use-by dates and the product itself (label, food category, net mass, etc.). On the other hand, it is hardly possible to accurately separate the packaging of products such as mustard in collapsible tubes, tightly sealed cans, sauces, or wet food residues wrapped in paper, from the product during the sorting process. The classification of products which cannot be separated from their packaging without the use of tools, or of highly contaminated packaging, to the category whose proportion by mass prevails conforms to general recommendations for sorting (cf. European Commission, 2004; ON, 2005). However, discrepancies occur when packaging which could be easily separated from its food contents or whose proportion by mass is higher than those of the contents, are subsumed under the category "food waste". In literature, no estimates are available about the dimension of included food packaging within food waste to date.

Furthermore, published studies provide little to no information about the consideration of food packaging. While some studies – for example by Schneider and Obersteiner (2007) or Salhofer et al. (2008) – have assumed that the quantity of packaging in the food waste category is negligible, WRAP (2008) provides inconsistent information; the form used in the on-site analysis by WRAP (2008) indicates that food was weighed in its packaging, but a note in the results section says that the mass of the packaging was not included. No further information is provided by WRAP (2008), about how the packaging was separated from its contents and how contamination because of moisture and food scraps was considered.

The present paper tries to bridge this gap of knowledge by estimating the dimension of food waste packaging which is included in the food waste category.

2.4. Screening

Screening, i.e. the sieving of waste before sorting, is another source of error in waste composition analyses (Dahlen and Lagerkvist, 2008). The sieving of waste with 40 and 10 or 20 mm mesh screens is often applied, in order to reduce the sorting effort (European Commission, 2004; Dahlen and Lagerkvist, 2008). For example Schneider and Obersteiner (2007) separated a sample of the category between 20 and 40 mm only into primary categories and did not differentiate the category <20 mm any further, which is prevalent practice. According to Dahlen and Lagerkvist (2008), the category <40 mm can contain a rather large proportion of food scraps and other biowastes, as well as other inorganic materials (e.g. cat litter, ashes, dusts). The results of a standard waste composition analysis of residual waste in a province of Austria (TBU, 2009) showed that the category <40 mm amounted on average to 30% by mass of the total residual waste and that the category 20–40 mm which amounted for 35% of the category <40 mm, consisted of 60% by mass of organic material. In order to minimize sources of error for food waste composition, waste should not be screened, the more so as RVA (2005b, cited by Dahlen and Lagerkvist, 2008) conclude that "sorting is generally manageable without sieving if applying a conscious handling of the waste", i.e. careful opening of bags and packaging in order to avoid dispersion of the contents such as cat sand, ashes, vacuum cleaner dust, flour, etc.

No estimates are available, how the screening of waste before sorting affects different food waste categories. It is assumed that screening leads to a significant underestimation of food waste categories such as preparation residues which are primarily composed of smaller scraps, whereas the influence on whole unused foods may probably be negligible. This hypothesis is investigated in a current project, by separating the screen underflow <40 mm into different food waste categories. Results will be available at the end of 2011. In the case study presented in this paper no screening was applied.

2.5. Limitations

Waste composition analyses give information about the composition of the analysed waste stream in percentage by mass or volume, but not directly about specific waste quantities by category. Data on waste quantities have to be obtained from waste statistics or by other methods (cf. WRAP, 2009a). Food disposed of via other disposal routes than the analysed waste stream, such as sewer, home composting, separate biowaste collection or fed to animals is not included. Furthermore, compared to other methods such as kitchen diaries or questionnaire surveys, an exact classification of individual food items is not always possible due to fragmentary information. However, waste composition analysis is a basic method for comprehensive studies (e.g. WRAP, 2008, 2009a) as well as for routinely scheduled waste composition analyses and therefore could be used easily for obtaining reliable and comparable data on food waste. In order to obtain estimates as accurate as possible, it is recommended to additionally analyse the contents of biowaste bins similarly as residual waste, and to include data on specific collection quantities.

3. Materials and methods

3.1. Model region

Fig. 1 shows the model region, a district in the northwest of Austria, which covers an area of 504 km^2 (Statistik Austria, s.a) and comprises 1 city with 58,500 inhabitants and 24 rural municipalities with overall 66,900 inhabitants (Statistik Austria, 2009). Facilities for the separate collection of wastes are available to all households. There are separate collection schemes for residual waste (kerbside); biowaste which is either collected kerbside via biowaste containers or treated by individual home composting, but can also be taken to civic amenity sites; plastics packaging and metals packaging (kerbside and at civic amenity sites); glass (bring scheme); paper (bring scheme); bulky waste (at civic amenity sites) and several other types of waste such as waste electrical and electronic equipment (WEEE), household hazardous waste, wood or cooking oils.

Table 2 shows the collection quantities of different types of municipal solid waste (MSW) in the model region. For the study, a differentiation between urban and rural municipalities was made due to the different structure of the municipalities. While the urban municipality consists of one single city which represents a separate administrative unit and is equivalent to a district, the rural district comprises 24 municipalities which respectively include small villages and towns. MSW is defined as waste from households, which municipalities are legally obliged to manage and waste from small commerce, services and institutions that produce waste comparable to household waste and are required for using the municipal collection scheme. Waste collected directly by the private sector not on behalf of municipalities is not included in Table 2.

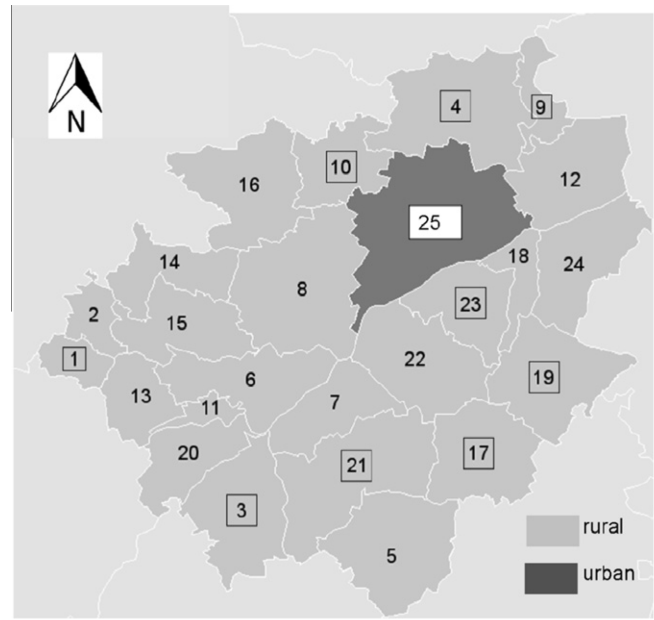

Fig. 1. Schematic map of the model region with its 24 rural municipalities and the urban municipality. The municipalities are symbolized by numbers. Framed numbers mark the sampled municipalities.

Table 2
Waste collection quantities from the urban and rural municipalities of the model region in the year 2008. (Source: Land Oberösterreich, 2009.)

	Per capita quantity (kg cap^{-1} yr^{-1})		Tonnage (t yr^{-1})	
	Urban	Rural	Urban	Rural
Residual waste	168	101	9839	6721
Recyclables	179	180	10,456	11,945
Biowaste[a]	103	94	6021	6234
Other waste[b]	21	36	1221	2384
Total	471	411	27,536	27,284

[a] Includes garden waste and food waste.
[b] Bulky waste, hazardous household waste.

3.2. Analysis design and procedure

The objectives of the case study were to determine the proportion and composition of food waste in residual waste containers from private households, to determine the influence of food packaging and to identify possible stratification criteria by analysing selected influencing factors. For this study, the definition of food waste by Monier et al. (2010) is used: Food waste is defined as raw or cooked food materials which include food loss before, during or after meal preparation in the household, as well as food discarded in the process of manufacturing, distribution, retail and food service activities. It comprises materials such as vegetable peelings, meat trimmings, and spoiled or excess ingredients or prepared food as well as bones, carcasses and organs (Monier et al., 2010). Not only food for human consumption but also pet food is included. Some food packaging is also included in the food waste category separated out from residual waste, due to procedural reasons (see Sections 2.3 and 4.3).

Sampling took place at household level, which means that collection containers (usually with a volume between 120 and 1100 litres) were selected by random and analysed separately. In order to obtain approximately equally sized units (cf. European commission, 2004), a sample volume of 120–240 litres was chosen, which means that the whole contents of 120 and 240 litre containers represented a sampling unit, whereas from a container with a volume of 770 or 1100 litres only a subsample of 240 litres was each analysed. These subsamples were obtained by randomly picking waste from the surface of the container into a 240 litres bin. The total number of sampling units (n) (see Table 3 and Eq. (1)) was calculated on the basis of a 95% confidence level (confidence coefficient CC = 1.96), data from past waste analyses (mean of the category food waste: 23.5% by mass, standard deviation: $\sigma = 17.1$) and an accepted maximum random sampling error of 12.5% which corresponds to a confidence interval (CI) of 2.9%, and was a compromise between statistical requirements and practical limitations. The calculation used the formula recommended by the Austrian standard for conducting waste composition analysis (ON, 2005) (Eq. (1)). Eq. (1) can be applied, provided that the quotient of the sample size (n) and the population (N) is lower than 0.05. Household waste composition analyses usually comply with this condition.

$$n = ((\sigma \cdot \mathrm{CC})/\mathrm{CI})^2 \tag{1}$$

The 130 samples were split into an urban and a rural sample, since prior studies revealed significant differences regarding food waste between urban and rural waste composition (e.g. Schneider and Obersteiner, 2007; Lebersorger and Salhofer, 2007). From the data of a prior waste composition study (Lebersorger and Salhofer, 2007), a higher variation coefficient for the proportion of food waste was obtained in the rural stratum (variation coefficient 0.84) than in the urban stratum (0.59). Therefore more sampling units were taken from the rural stratum. The number of samples per stratum was scheduled deliberately (Table 3).

The sample units were selected in two steps. At first, a representative sample of 9 rural municipalities was pre-selected. Then the addresses from which a sample had to be taken were selected by random selection (random numbers) from the address lists of residual waste containers. In the urban stratum, samples from smaller (120 or 240 litres) containers and larger containers (770 or 1100 litres) were selected separately in order to avoid underrepresentation of larger containers which are predominantly provided at multi-family dwellings. The selected addresses included the calculated minimum number of sampling units plus an additional reserve of about 40% of the sample size. This reserve was provided for, in case a sample had to be rejected, due to, e.g. a too small sample mass or not meeting the quality criteria (see below). All samples were picked up on the eve of regular waste collection days between May 7 and 27, 2009. In doing so, the filling degree and information about the house type (single or multi-family dwelling) were entered into a documentation sheet. The sorting process took place from May 12 to 15 and on May 26 and 27. Table 3 shows the number of analysed samples. In order to assure high data quality, data sets which showed more than 3% deviation of the total sample mass from the sum of the masses of the individual waste categories, were excluded from the further analyses, according to the requirements of the standard concerning waste composition analysis edited by the Austrian Standards Institute (ON, 2005).

The sorting process was conducted in two steps:

- At first, residual waste was sorted by hand into 10 categories (paper, glass, metal, WEEE and household hazardous waste, plastics and composites packaging, garden waste, preparation residues compostable, preparation residues not compostable, avoidable food waste, rest) without precedent screening.
- And subsequently the category avoidable food waste was analysed in detail for each sample.

From each product of the category avoidable food waste a photo was taken, the product was weighed and the following information was entered into a spreadsheet in MS Excel: the name of the product, its brand name, product category (22 categories were defined, e.g. vegetables, meat, bread...), its life cycle stage (see Fig. 2), its gross mass (for packaged products) and/or net mass (for loose products), an estimation of the current filling level, and – if available and legible – also information about best-before and use-by dates, date of packing, purchasing price, and original mass/quantity of its contents. Product packaging was separated from its contents and was weighed separately with an accuracy of ±0.1 g, unless there was a time shortage or separation required significant effort. This database enables the analysis of the data according to diverse criteria.

For the analysis of the data the program packages MS Excel 7.0 and SPSS 15.0 were used.

3.3. Classification of food waste

A classification system for food waste with 3 levels of subcategories was developed (Fig. 2). The basic idea behind it was to enable a classification which is clear, unambiguous and as easy as possible, and to minimize the scope for subjective interpretation. The differentiation between avoidable and non-avoidable food waste was made with regard to the theoretical prevention potential (cf. Salhofer et al., 2008). While preparation residues are regarded as unintended by-products and therefore not avoidable, food which has been purchased but not been used for the intended purpose (eating, drinking) is considered avoidable. Cultural or individual differences, e.g. whether it is necessary to peel a cucumber, an apple or potatoes, or the question which leaves of vegetables or lettuce could be used, make classification intricate. As most of these considerations reflect common and individual eating

Table 3
Calculated, sorted and finally analysed numbers and mass of sampling units.

	Rural stratum		Urban stratum		Total	
	Sample units	Mass (kg)	Sample units	Mass (kg)	Sample units	Mass (kg)
Calculated	70	–	60	–	130	–
Sorted	87	1277.3	68	1166.1	155	2443.4
Rejected	14	138.3	4	49.9	18	188.2
Analysed	73	1139.0	64	1116.2	137	2255.2

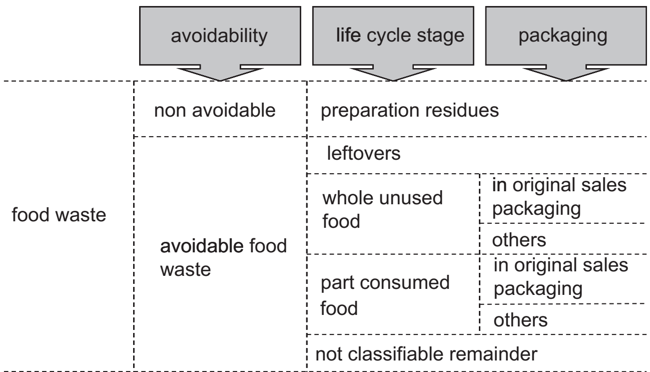

Fig. 2. Classification of food waste used in the study (see Section 3.3 for definition of terms).

behaviour, but do not result from too much buying, such food items were allocated to "preparation residues" or "leftovers" according to common Austrian eating tradition.

Preparation residues are biowastes that are generated in the course of food preparation. They comprise parts of food which are inedible or which usually are not consumed, such as outside leaves of lettuce, peelings, apple cores, bones, eggshells, coffee grounds including coffee filters or teabags. Preparation residues are considered not avoidable and were therefore not further analysed in detail.

Leftovers are foods post-preparation/consumption and comprise food which has been bitten into, prepared food or food consisting of different components which has been served before, as well as convenience food which has already been prepared for instantaneous consumption by cooking, warming or baking. Leftovers are considered mostly avoidable. Non-avoidable leftovers are, for example, the bones of a roasted chicken with remaining skin and/or meat on it or used chewing gum.

Whole unused and part consumed food cannot be distinguished precisely, because information from waste is only fragmentary. One and the same product might have been purchased in different forms (not packed, individual sales-packaging, service packaging, six-pack, etc.) which can only be identified clearly if it had been disposed of in its packaging. For this reason, the presence of the original sales packaging was introduced as a secondary criteria in order to distinguish whether food was found in its original packaging and could be unambiguously classified, or whether the available information was incomplete (see Table 4). The original sales packaging was defined as packaging which is usually applied before a product is displayed for sale, that means either primary packaging by food industry (e.g. for flour, vegetables, canned foods) or packaging for parts of larger items such as meat or cheese which have been chopped into smaller units and packed at the point of sale. All packaging which is directly added during the selling process by shop-assistants or by the consumers themselves, such as service packaging (for meat, take-away food) or bags (e.g. for fruits, bread) were not considered as original sales packaging. This differentiation was made with regard to identifiability. As original sales packaging is usually sealed, whole unused food can be unambiguously distinguished from food in opened packages, whereas no information is available about whether the amount of, e.g. apples or bread which has been put into an unsealed bag by the consumers themselves represents the originally bought quantity or only part of it.

All food items which could not be classified into any of the subcategories of avoidable food waste were subsumed to the category "not classifiable remainder" which comprises tiny, not identifiable pieces, tiny pieces which have been classified by mistake as food waste in the first step (e.g. some preparation residues) or have been left over in the second step of sorting such as tiny pieces of packaging and drugs. Therefore, the category "not classifiable remainder" may also include some percentages of non-avoidable food waste. This percentage was considered negligible since the category "not classifiable remainder" already amounts for only a very small percentage of avoidable food waste.

3.4. Determining the proportion of food packaging

The mass of food packaging which was included in the category avoidable food waste was estimated on the basis of the data which had been registered for each product. Overall 2262 products could be identified, of which 44% were without packaging. The mass of food packaging was determined by weighing if the packaging could be easily separated from the contents (see also Section 3.2), which was the case for 19% of products. For another 18% of products, the mass of the packaging was calculated on the basis of information imprinted on the packaging (original mass and quantity) and the current fill level estimated at the sorting process. For the remaining 19% of products without any information imprinted on the packaging, the mass of packaging was estimated by taking the mass of the packaging of similar products.

The percentage of packaging per product category and per life cycle stage were calculated as the quotient of the sum of packaging masses and the overall mass of the product category and accordingly life cycle stage.

4. Results and discussion

4.1. Waste composition

Table 5 shows the proportion of non-avoidable preparation residues and avoidable food waste in residual waste for urban and rural strata. The values for the total region were calculated as weighted means from the means of the two strata, using the absolute tonnage of residual waste per stratum as weighting factors

Table 4
Classification of whole unused and part consumed food.

Category	Definition	Examples
Whole unused food in original sales packaging	Food in its originally sealed unopened sales packaging	Originally sealed chocolate box, unopened cup of yoghurt, apples in original sealed sales packaging, pack of meat
Whole unused food, others	Individually wrapped food items which are part of a larger sales packaging or whole item of food which is unpacked or available by piece	Several wrapped bonbons, 1 unopened cup of yoghurt if it is usually sold in six-packs, one loose apple, a cucumber, piece of meat
Part consumed food in original sales packaging	Food in its original sales packaging which has been opened and part consumed	Open chocolate box, part consumed cup of yoghurt, open package of meat, 4 apples in their original six-pack
Part consumed, others	Whole single items of a food which is usually sold bunched, cut food, part consumed food in packaging other than original sales-packaging	Single mushrooms, single radish, slice of bread, slice of an apple, part consumed salad in service packaging

Table 5
Mean percentages and confidence intervals of food waste in residual waste, differentiated by stratum and stratified result for the total region (in % by mass).

	Rural stratum	Urban stratum	Total region
Preparation residues (% by mass)*	8.3 ± 2.1	12.9 ± 2.0	11.0 ± 1.46
Avoidable food waste (% by mass)*	10.3 ± 2.7	16.6 ± 2.8	14.1 ± 2.0
Σ food waste (% by mass)*	18.6 ± 3.7	29.5 ± 3.5	25.1 ± 2.6

* Significant difference between the strata, $p < 0.001$ (Mann–Whitney *U*-test).

(urban: 0.59; rural: 0.41; obtained from Table 2). The relative accuracy for the category food waste, which is the quotient of the width of the confidence interval and the mean, is 12.1% for the total region. This means that the targeted accuracy (12.5%, see Section 3.2) was achieved. In the urban stratum, the relative accuracy amounts for 11.9% and in the rural stratum for 19.8%, which corroborates the underlying assumption of rural municipalities being more heterogeneous. Both values are lower than 20% which is the upper bound of the accuracy recommended by the European Commission (2004), and therefore meet the quality standard.

There is a significant difference between the urban and rural stratum, as can be deduced from the result of the Mann–Whitney *U*-test and the confidence intervals which are not overlapping. Residual waste from urban areas contains a significantly higher proportion of both preparation residues and avoidable food waste.

The difference becomes even more prominent if specific quantities are considered (see Table 6) due to higher specific quantities of residual waste in urban areas. The specific quantities of food waste in Table 6 were calculated by multiplying the composition in percent by mass (see Table 5) with the specific quantity of residual waste in the year 2008 (data source: Land Oberösterreich, 2009) for each stratum. It must be pointed out that the quantity of residual waste reported by waste statistics also includes unknown amounts of waste from small commerce, services and institutions. The quantity of residual waste originating only from private households is therefore unknown for that region. Usually the influence of non-household waste is higher in urban than in rural areas. In 2001, there were 0.35 places of employment per inhabitant in the rural stratum of the study area, compared to 0.69 in the urban stratum (Statistik Austria, 2005). Thus, part of the difference presumably can be attributed to the influence of waste which is similar to household waste but originates from other sources.

4.2. Influencing factors

Influencing factors were investigated in order to identify possible stratification criteria. Beside the influence of settlement structure (rural/urban) also house type (single or multi-family dwelling) and availability of a container for the collection of biowaste on the property were investigated. Each building with more than two flats was regarded as multi-family dwelling. 51.6% of the sampled buildings in the urban stratum were multi-family dwellings and 16.0% in the rural stratum. As can be seen in Table 7, residual waste from multi-family dwellings contains a significant higher percentage of avoidable food waste and overall food waste. Overlaps with the influence of settlement structure cannot be entirely excluded since multi-family dwellings are more prevalent in the urban area.

Table 6
Mean specific quantities and confidence intervals of food waste in residual waste, differentiated by stratum and stratified result for the total region (in kg cap^{-1} yr^{-1}).

	Rural stratum	Urban stratum	Total region
Preparation residues (kg cap^{-1} yr^{-1})*	8.3 ± 2.1	21.7 ± 3.3	14.6 ± 1.9
Avoidable food waste (kg cap^{-1} yr^{-1})*	10.4 ± 2.7	27.9 ± 4.7	18.7 ± 2.7
Σ food waste (kg cap^{-1} yr^{-1})*	18.8 ± 3.8	49.6 ± 5.8	33.3 ± 3.4
Total amount of residual waste (kg cap^{-1} yr^{-1})	101	168	133

* Significant difference between the strata, $p < 0.001$ (Mann–Whitney *U*-test).

Data about availability of a biowaste container were available from the local authorities for all but 10 datasets (one municipality). Based upon the results of prior studies (Lebersorger et al., 2005), less preparation residues but no significant different proportion of avoidable food waste was expected to be found in residual waste, if a container for biowaste was available. As Table 8 illustrates, both hypotheses had to be rejected. There is no difference in the proportion of preparation residues in residual waste, and the proportion of avoidable as well as of total food waste is significantly higher for households with a biowaste container. The investigated relationship is presumably incomplete, since home composting which is an important influencing factor, specific quantities of residual waste and interaction effects were not considered. Specific quantities of residual waste are likely to be higher for households with home composting than for households using a biowaste container, and are the highest for households with neither of them (cf. Lebersorger et al., 2005). The preference for home composting or a biowaste container is influenced by settlement structure; 31.3% of the households of the rural stratum of the sample had a container for biowaste on the property and 66.7% of the urban stratum. As for house type, 32.9% of the single-family dwellings had a biowaste container and 81.0% of the multi-family dwellings.

In order to obtain an indication about potential interaction effects, factorial analyses of variance were calculated with the independent factors stratum, house type and availability of a container for biowaste, which had two factor levels each, so that overall 8 different groups were analysed. The assumptions for a factorial analysis of variance were not fully met, because the proportion of preparation residues was not normally distributed in 3 of the 8 groups, and the proportion of avoidable food waste was not normally distributed in 2 groups. The analysis revealed no significant effects on the proportion of preparation residues and only a significant main effect of the stratum on avoidable food waste. No interaction effects were significant in either of the models.

Table 7
Mean percentages and confidence intervals of food waste in residual waste (in % by mass) differentiated by type of dwelling, and significance of Mann–Whitney *U*-test.

	Single family ($n = 92$)	Multi family ($n = 45$)	Significance
Preparation residues (% by mass)	9.8 ± 1.9	11.7 ± 2.4	0.080
Avoidable food waste (% by mass)	11.9 ± 2.6	16.1 ± 3.1	0.008*
Σ food waste (% by mass)	21.6 ± 3.3	27.9 ± 4.6	0.024*

* Significant.

Table 8
Mean percentages and confidence intervals of food waste in residual waste (in % by mass) differentiated by availability of a container for biowaste on the property, and significance of Mann–Whitney *U*-test.

	Container for biowaste on the property		
	Not available ($n = 65$)	Available ($n = 62$)	Significance
Preparation residues (% by mass)	9.8 ± 2.3	10.7 ± 2.0	0.321
Avoidable food waste (% by mass)	9.9 ± 2.5	16.6 ± 3.1	0.001*
Σ food waste (% by mass)	19.8 ± 3.6	27.3 ± 4.2	0.014*

* Significant.

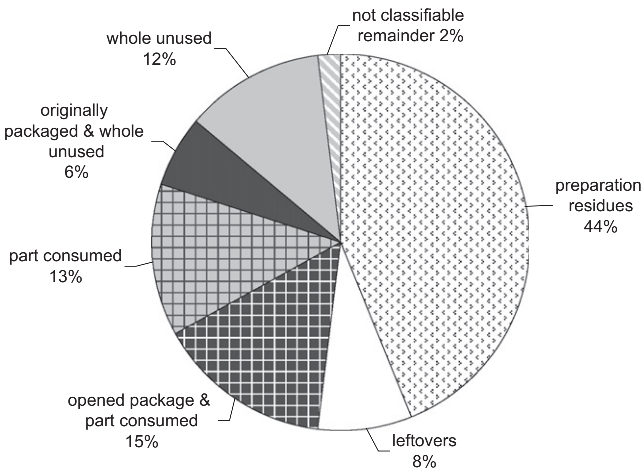

Fig. 3. Composition of food waste by life cycle stage (percent by mass), in the studied region.

4.3. Composition of food waste

Fig. 3 shows the composition of food waste by life cycle stage for the studied region in percent by mass. The subcategories part consumed and whole unused food do not differ significantly between the urban and the rural stratum, whereas leftovers were found in a significantly higher proportion in the urban stratum.

The proportions of the secondary categories are comparable to those found by Langley et al. (2010), though their study was conducted in the UK and used consumer self-measurements. They found that preparation by-products amounted to 33% of food waste and "post-preparation" (equivalent to leftovers in our study) to 15%. Given a certain ambiguity between these two categories, the sum of both categories would be nearly the same in both studies. As for wasted food, Langley et al. (2010) determined 12% of whole unused food and 37% of part consumed food.

Table 9 shows the composition of avoidable food waste by product categories. Significant differences between the urban and rural stratum were found for prepared meals from diverse components, drinks and salty snacks, which showed higher percentages in the urban stratum. Though comparability with other studies is limited, this study agrees with the conclusion by Parfitt et al. (2010) that it is the most perishable food items that account for the highest proportion of food waste.

4.4. The influence of food packaging

Table 9 shows the percentage of food packaging which was included in the respective product category because of methodological reasons (see Sections 2.3 and 3.4). Food packaging can amount to a significant proportion of some waste categories such as jams and sauces which are mainly packed in jars, or tea and spices whose product mass is relatively low compared to its packaging. Also the life cycle stage of a food item has an impact, since the mass of food packaging in relation to the mass of the food itself is higher if the food has been part consumed or if the food item lost water content during storage (see Table 10). However, the mentioned product categories only amount to very small percentage of overall food waste and thus the mass of their packaging is of virtually no consequence. Overall, food packaging amounts to 8% by mass of avoidable food waste. This value is very low compared to the contamination of other waste categories with moisture, food scraps and dirt. Bauer (2002) found that contamination amounted to 14% by mass for paper in residual waste and to 27% by mass for plastics packaging. However, values of up to 55% and even higher are reported in the literature (Bauer, 2002; Dahlen and Lagerkvist, 2008). No contamination adjustment was made in our study.

Table 11 displays the net quantities of avoidable food waste which were calculated on the basis of the net masses of avoidable food waste for each dataset. The inclusion of some food packaging in the category "avoidable food waste" does not change the results significantly, as can be seen by the overlapping confidence intervals by a comparison of the data in Table 11 with Table 5 and respectively Table 6. Hence, it can be concluded that the proportion

Table 9
Composition by product category (100% = mass of avoidable food waste) and percentage of included food packaging (100% = mass of the respective product category).

Product category	Composition by product category (% by mass of avoidable food waste)	Proportion of food packaging (% by mass of the product category)
Vegetables	17.7	7
Bread	15.3	2
Confectionary and desserts	11.7	7
Meat	10.9	7
Fruit	8.6	2
Dairy products	7.5	16
Cheese	4.6	7
Prepared meal from diverse components	2.9	4
Ready-to-serve-meal	2.6	18
Sandwiches	1.9	2
Pasta and rice	1.9	3
Jam	1.7	52
Baking ingredients and cereals	1.5	7
Beverages	1.5	24
Sauces	1.4	33
Spices and herbs	1.2	25
Salty snacks (peanuts, potato chips...)	0.9	11
Spread and similar delicatessen	0.8	23
Eggs	0.6	1
Pet food	0.5	20
Tea	0.1	26
Others	4.2	9
Avoidable food waste	100.0	8

Table 10
Percentage of included food waste packaging at different life cycle stages.

Life cycle stage of food	Percentage of packaging (% by mass)
Originally packaged and whole unused	11
Whole unused	2
Opened package and part consumed	18
Part consumed	3
Leftovers	2
Not classifiable remainder	2

Table 11
Proportion and specific quantity of avoidable food waste excluding food waste packaging in residual waste (means and confidence intervals).

Avoidable food waste excl. food packaging	Rural stratum	Urban stratum	Total region
% by mass	9.4 ± 2.6	15.2 ± 2.6	12.8 ± 1.9
kg cap^{-1} yr^{-1}	9.5 ± 2.6	25.5 ± 4.4	17.0 ± 2.5

of food waste packaging can be neglected and that the common practice of classifying packed food together with their packaging into the category "avoidable food waste", is admissible. The inclusion of some food waste packaging will hardly cause an overestimation of the food waste category, since on the other hand some food scraps adhering to other materials as contaminants and very small food scraps in the fines category cannot be captured by manual sorting and will therefore not be included in the food waste category.

5. Conclusions

Composition analyses of residual waste provide an opportunity for obtaining data about food waste at local and regional levels. This opportunity has been increasingly used, but the methods and results of these studies are not really comparable, because different definitions and approaches have been applied. Moreover, published studies often lack substantial information and are therefore not reproducible. Based upon a literature review and a case study, this paper has discussed a methodology for determining the proportion of food waste as part of a waste composition analysis. The most important adaptations which are necessary for obtaining comparable data concern sieving prior to sorting and the classification of packaging with food contents.

Sieving waste before sorting entails a loss of information and mass and should therefore not be applied. Sieving separates food waste from its (opened) packaging which can no longer be classified correctly into subcategories of food waste and increases the proportion of fines considerably. Findings from the literature as well as practical experiences of the authors indicate that sorting is manageable without sieving, if the waste is handled carefully, which means that bags and packaging should be carefully opened in order to avoid dispersion of the contents.

Packed food waste should not be separated from its packaging, but should be classified into the food waste category together with its packaging in order to avoid a loss of information. The case study showed that the proportion of food packaging included in the food waste category amounted to only 8%. Significant influences of food waste packaging were only found for product categories such as jams and sauces, but whose proportion in residual waste were insignificant. The overall influence can therefore be disregarded, the more so as usually adjustments for the influence of contaminations (moisture, food scraps, dirt) on other waste categories such as paper or plastics packaging, which amount to much larger percentages of the contaminated category, are not made either.

Secondary categories of food waste should at least differentiate between non-avoidable food waste (preparation residues) and avoidable food waste. Depending on the specific research question, further subcategories can be defined by diverse criteria, provided that they can be unmistakably merged to the categories of the superior level and that the classification scheme is reproducible. Difficulties in practice occur because analyses of residual waste only provide fragmentary information about individual items of food waste. The case study tried to find an objective classification by life cycle stage by introducing the type of food packaging (in its original sales packaging or not) as additional criterion.

Waste composition studies provide a data base about the proportion of food waste, though they are not able to cover all aspects. The results of the case study indicated a significant higher proportion of preparation residues and avoidable food waste in urban than in rural areas, and a significantly higher proportion of avoidable food waste in residual waste from multi-family dwellings. However, no conclusions could be deduced about the influence of the availability of a biowaste container on the property, for which additional information about collection quantities of residual waste and biowaste, composition of separately collected biowaste and home composting would be required. The results from the case study suggest stratifying a sample into urban and rural strata.

There are still some important facts which could be discussed to include all different international cases. In order to foster further discussion, a task group of the International Waste Working Group on Prevention of Food Waste is in foundation phase (for further information see http://iwwg.eu/task-groups/food-waste).

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