Updating and testing of a Finnish method for mixed municipal solid waste composition studies

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Abstract

More efficient recycling of municipal solid waste (MSW) is an essential precondition for turning Europe into a circular economy. Thus, the recycling of MSW must increase significantly in several member states, including Finland. This has increased the interest in the composition of mixed MSW. Due to increased information needs, a method for mixed MSW composition studies was introduced in Finland in order to improve the national comparability of composition study results. The aim of this study was to further develop the method so that it corresponds to the information needed about the composition of mixed MSW and still works in practice.

A survey and two mixed MSW composition studies were carried out in the study. According to the responses of the survey, the intensification of recycling, the landfill ban on organic waste and the producer responsibility for packaging waste have particularly influenced the need for information about the composition of mixed MSW. The share of biowaste in mixed MSW interested the respondents most. Additionally, biowaste proved to be the largest waste fraction in mixed MSW in the composition studies. It constituted over 40% of mixed MSW in both composition studies. For these reasons, the classification system of the method was updated by further defining the classifications of biowaste. The classifications of paper as well as paperboard and cardboard were also updated. The updated classification system provides more information on the share of avoidable food waste and waste materials suitable for recycling in mixed MSW. The updated method and the information gained from the composition studies are important in ensuring that the method will be adopted by municipal waste management companies and thus used widely in Finland.

Keywords
Mixed municipal solid waste, waste composition, waste classification, Finland

1 Introduction

The recycling target for municipal solid waste (MSW) was introduced in the waste framework directive (2008/98/EC) of the European Commission. By 2020, preparing for the reuse and recycling of MSW should be increased to 50% (European Commission Directive, 2008/98). In December 2015, the European Commission adopted an ambitious Circular Economy Package to stimulate Europe’s transition towards a circular economy. The Circular Economy Package aims to boost global competitiveness, foster sustainable economic growth and generate new jobs by means of new legislative proposals on waste. By 2030, the recycling of MSW must be increased to 65%. The corresponding target for packaging waste is 75%. (European Commission, 2016.)

In Finland, the aim was to achieve a 50% MSW recycling rate by the end of 2016 (Ministry of the Environment, 2008). However, in 2014, only 33% of MSW was recycled in Finland (Statistics Finland, 2015a). Since the recycling of MSW has not increased significantly during the past two years, it is evident that the Finnish recycling target will not be reached. In order to achieve the 50% recycling target by 2020, let alone the new recycling target of the Circular Economy Package, Finland has to increase substantially the recycling of MSW in the following years.

Due to MSW recycling targets, interest in the composition of mixed MSW has increased in recent years. Mixed MSW refers to the remaining part of MSW after the source separation of different waste fractions (e.g. biowaste, paper, cardboard, glass and metal, which are typically source separated in Finland). Mixed MSW comprises a major part of the total amount of MSW. For instance, in 2014, 51% of MSW in Finland was mixed MSW (Statistics Finland, 2015a). There is a great deal of additional recycling potential in Finnish mixed MSW. The additional recycling potential concerns particularly biowaste, cardboard and plastic since they comprise approximately 65% of Finnish mixed MSW (Finnish Solid Waste Association, 2016). Thus, more efficient source separation of these fractions would substantially increase the recycling rate of MSW.

Information on the composition of mixed MSW is needed in the planning and environmental assessment of waste management at both the regional and national level (Edjabou et al., 2015; Sharma and Mcbean, 2007). In Finland, particularly the landfill ban on organic waste from 2016 onwards and the producer responsibility for packaging waste have increased the interest in the composition of mixed MSW. Additionally, information on the composition of mixed MSW can be utilised in many other purposes which are more specific. The comparison of different waste collection systems (Dahlén et al., 2007), the determination of various combustion properties (e.g. Horttanainen et al., 2013; Zhou et al., 2014), the planning and establishment of waste treatment plants (Gidarakos et al., 2006), the life cycle assessment of waste management systems (Slagstad and Brattebø, 2013) as well as the quality control of waste (Petersen et al., 2005) are specific examples where detailed and accurate information about the composition of mixed MSW has been needed and utilised.

The composition of mixed MSW can be determined through a composition study, i.e. manually sorting waste fractions to different categories. Internationally, studies have been carried out in various methods (e.g. Aphale et al., 2015; den Boer et al., 2010; Burnley et al., 2007; Cornelissen and Otte, 1995; Dahlén et al., 2007; Edjabou et al., 2015; Gidarakos et al., 2006; Horttanainen et al., 2013; Hristovski et al., 2007; Petersen et al., 2005; Sharma and McBean, 2007; Zhou et al., 2014). The variety of methods used is due to e.g. different source separations systems, sorting guidelines, waste collection systems and information needed about the composition of mixed MSW. The European Commission (2004) has also introduced its own method for solid waste composition studies. In a review by Dahlén and Lagerkvist (2008), altogether 20 different methods for mixed MSW composition studies were identified. Even though various methods for mixed MSW composition studies exist, the use of methods has not always generalised nationally, e.g. in Finland, let alone internationally.

Due to the increased need for information about mixed MSW, a number of mixed MSW composition studies have been conducted in Finland. It has been evaluated that at least 30 mixed MSW composition studies have been carried out in Finland since 1987. The majority of these studies have been conducted in the 2000s. (Sahimaa et al., 2015.) However, studies have been carried out with different methods, which makes it difficult to compare the results. For instance, sample sizes, number of samples, classification methods and stratification practices vary substantially between studies. Therefore, it is challenging to form an overall picture of the composition of mixed MSW in Finland.

A method for mixed MSW composition studies was published in Finland at the end of 2014 by Toivonen and Sahimaa (2014) in order to improve the national comparability of composition study results. Additionally, the method and its development have been discussed in a study by Sahimaa et al. (2015). The method includes several guidelines concerning the planning and implementation of composition studies as well as the analysis of results. Because the method has been published only recently, there are no experiences of how it works in practice.

In this study, the Finnish method for mixed MSW was further developed based on the results of a survey and two mixed MSW composition studies. The updating of the method focused on the classification of waste fractions since it was estimated to need further development after surveying the information needs concerning the composition of mixed MSW and testing the method in practice. The method's other guidelines (i.e. guidelines for stratification, sampling, statistical analysis) were not updated since they are in line with the recommendations of the European Commission (2004).

The research questions were the following:

1) What information do different operators in the waste sector need about the composition of mixed MSW?

2) How does the method work in practice and what is the composition of mixed MSW in two case areas, Riihimäki and Turku?

3) How should the classification and sorting guidelines of the method be updated so that the method corresponds to the information needs about mixed MSW and is still applicable in practice?

2 Materials and methods

2.1 Description of the Finnish method for mixed MSW composition studies

The method for Finnish mixed MSW composition studies contains altogether 15 recommendations for the planning and implementation of composition studies as well as the analysis of results. The recommendations concern e.g. sampling, the number of samples, sample size, sorting, classification of waste fractions, safety and statistical analysis (Toivonen and Sahimaa, 2014). The classification of waste fractions is a particularly important part of the method since it defines the information obtained through a composition study. Thus, if classifications of waste fractions vary substantially between composition studies, results can hardly be compared (Dahlén and Lagerkvist, 2008).

In the classification of fractions, waste categories are divided into primary, secondary and tertiary levels. Since the levels are hierarchical (i.e. second and third level categories are included in the higher level categories), the results of composition studies are always comparable at least at the first level. At the first level, the classification is determined on the basis of waste materials (e.g. paper, wood, metal and glass). Additionally, the first level includes categories for textiles, shoes and bags, hazardous chemicals, miscellaneous waste as well as waste electrical and electronic equipment (WEEE) and batteries. At the second level, the classification is determined according the waste fractions' origin (e.g. kitchen waste) and the purpose of use (e.g. paper packaging). Thus, the total share of packaging waste in mixed MSW can be determined at the second level. At the third level, certain second level categories are further classified on the basis of certain characteristics. For instance, plastic packaging is classified to dense and plastic film packaging. The number of categories depends on the level of classification (11, 27 and 38). There is no category for hazardous waste in the classification system since hazardous waste may consist of different materials and products. Instead, different hazardous waste categories are clearly marked in the classification, and the total amount of hazardous waste can be calculated by adding up different categories' masses. (Sahimaa et al., 2015.) The classification system is presented in Table 1.

Table 1
Classification of waste fractions in the method (Sahimaa et al., 2015).

Level 1	Level 2	Level 3
1. Biowaste	1.1 Kitchen waste	
	1.2 Garden waste	1.2.1 Sticks and branches
		1.2.2 Other garden waste
	1.3 Other biowaste	
2. Paper	2.1 Paper packaging	
	2.2 Non-packaging paper	2.2.1 Producer responsibility paper
		2.2.2 Other non-packaging paper
3. Paperboard and cardboard	3.1 Paperboard packaging	3.1.1 Aluminium-layered paperboard packaging
		3.1.2 Other paperboard packaging
	3.2 Cardboard packaging	
	3.3 Non-packaging paperboard and cardboard	
4. Wood	4.1 Wood packaging	
	4.2 Treated wood[a]	
	4.3 Untreated non-packaging wood	4.3.1 Construction and demolition wood
		4.3.2 Other untreated non-packaging wood

5. Plastic	5.1 Plastic packaging	5.1.1 Dense plastic packaging
		5.1.2 Plastic film packaging
	5.2 Non-packaging plastic	5.2.1 Non-packaging dense plastic
		5.2.2 Non-packaging plastic film
6. Glass	6.1 Glass packaging	
	6.2 Non-packaging glass	
7. Metal	7.1 Metal packaging	7.1.1 Aluminium packaging
		7.1.2 Other metal packaging
	7.2 Non-packaging metal	
8. Textiles, shoes and bags	8.1 Shoes and bags	
	8.2 Textiles	8.2.1 Clothes
		8.2.2 Other textiles
9. WEEE and batteries	9.1 WEEE	9.1.1 Fluorescent tubes, low energy and LED light bulbs[a]
		9.1.2 Other WEEE
	9.2 Small batteries[a]	
	9.3 Automotive accumulators[a]	
10. Hazardous chemicals[a]	10.1 Medicines[a]	
	10.2 Other hazardous chemicals[a]	
11. Miscellaneous waste	11.1 Miscellaneous packaging	
	11.2 Diapers and sanitary protectors	
	11.3 Other miscellaneous waste	11.3.1 Other combustible waste
		11.3.2 Rubble
		11.3.3 Other non-combustible waste

[a] Hazardous waste.

2.2 Survey on the need for information on mixed MSW

In the former development of the MSW composition study method by Sahimaa et al. (2015), the information needs of different waste management authorities concerning mixed MSW were taken into account through a survey and interviews. A survey was sent to 35 different Finnish municipal waste management companies. Nevertheless, the information needs of many important stakeholders, such as waste operators in the private sector, were not taken into consideration by Sahimaa et al. (2015). Therefore, another survey was performed in this study in order to ensure that the information needs of the Finnish waste sector are comprehensively taken into account in the method.

The aim of this survey was to determine what information is needed by different operators in the waste sector about the composition of mixed MSW and what points require improvement in the classification system of the method. The survey was sent via email to 51 persons from 35 different organisations, such as producer responsibility associations, waste management companies, research institutes, private service companies, consultants and waste incineration plants. The organisations chosen in the survey were either research partners or other significant stakeholders in the Finnish waste sector. Respectively, the survey was sent to either managing directors or other experts (e.g. environmental engineers, researchers and operation managers) if detailed contact information was available. To ensure a sufficient number of responses, the survey was sent to one to four persons per organisation. In large organisations, the survey was sent to several persons.

The survey consisted of several open and multiple choice questions. At first, the need for information on the composition of mixed MSW was investigated by asking the respondents to choose the waste categories whose share in mixed MSW they were interested in. After that, the potential need to improve the classification system was identified by several questions. For instance, respondents were asked to assess on a scale of 1 to 5 (1 = very poorly, 5 = extremely well) how well the classification corresponds to their need for information about the composition of mixed MSW and to identify the categories most in need of improvement. The survey questions are presented in Supplementary material A.

2.3 Mixed MSW composition studies for the testing of the method

After the survey, two mixed MSW composition studies were conducted in the late winter of 2015. The primary objective of the studies was to investigate how the method and particularly its classification system work in practice. The objective was also to define the composition of mixed MSW in two case areas, Riihimäki and Turku. Riihimäki is a rather small city in Southern Finland with approximately 30 000 inhabitants (Statistics Finland, 2015b). Turku, in contrast, is a considerably larger city in Southwest Finland. The population of Turku is approximately 180 000 inhabitants (Statistics Finland, 2015c). Paper, cardboard, glass and metal are recommended to be source separated in both case areas. In Riihimäki, the source separation guidelines concern also biowaste. Biowaste is source separated in residential buildings of more than five apartments (Kiertokapula Oy, 2016). In contrast, the source separation of biowaste is required only in institutional kitchens in Turku (Turun Seudun Jätehuolto Oy, 2015).

The composition of mixed MSW was determined according to the third level of classification in both studies. According to Lagerkvist et al. (2011), sorting should be carried out stepwise if waste samples are sorted into more than a dozen categories. Therefore, sorting was carried out in two phases so that certain categories were first sorted according to the first level and thereafter according to the third level of classification. Other categories were sorted directly according to the third level. This sorting practice was not instructed in the method. Because sorting was rather elaborate due to a large number of waste categories, sorting instructions were provided to the sorters in advance. Furthermore, a lecture concerning sorting and safety issues in composition studies was held for the sorters.

All recommendations and guidelines of the method could not be followed in the composition studies due to time and cost constraints. These recommendations concerned stratification and the number of samples. Nevertheless, the recommendations and guidelines regarding sorting were followed precisely since the primary objective of the composition studies was to investigate particularly how the classification system works in practice. Since stratification was not applied (i.e. sampling form normal waste collection trucks) in the studies although it is recommended, approximately 35 samples should have been sorted in both studies in order to reach the recommended level of accuracy for the results (Toivonen and Sahimaa, 2014). However, only eight and 22 samples were sorted in the studies. Additionally, the fine fraction was not treated according to the method. The method recommends that the total mass of the fine fraction should be divided based on a visual estimate to different categories after the sorting regardless of whether the samples are sieved or not (Sahimaa et al., 2015). Waste samples were not sieved in the studies. Therefore, only the mass of the unidentified fine fraction was divided based on a visual estimate to different categories after the sorting, and the identified fine fraction was manually sorted according to its material in order to minimise the uncertainty related to the visual estimation.

The results of the composition studies are presented as average proportions of waste categories in mixed MSW. Additionally, the standard deviations and coefficients of variation (i.e. standard deviation divided by the mean) of the results are presented. The results were analysed by the Shapiro-Wilk test and the Mann-Whitney U test. The Shapiro-Wilk test was applied to verify the normal distribution of the composition data (*p*-value more than 0.05 indicated a normal distribution) (Mardia, 1980). The Mann-Whitney U test on a 95% confidence level was respectively applied to identify differences in the distributions of waste categories among the case areas (*p*-value less than 0.05 indicated a significant difference) (Brunner and Puri, 1996). The analyses were carried out using SPSS Statistics Version 23.

3 Results and discussion

3.1 Survey results

A total of 28 persons from 22 organisations responded to the survey. The response rate of the survey was 55%. Even though the respondents represented different types of organisations, there were no distinguishing features in the responses between different organisations types. Most responses were received from producer responsibility associations, waste management companies, research institutes and waste incineration plants. Together they constituted 79% of the responses. According to the responses, of all first level categories, the share of biowaste in mixed MSW interested the respondents most. Of the second level categories, the following categories were considered the most interesting: kitchen waste, cardboard packaging, treated wood, plastic packaging, metal packaging, other metal and miscellaneous packaging. Of the third level categories, the share of both plastic packaging categories (dense film packaging and plastic film packaging) in mixed MSW interested the respondents most. Hence, respondents' information needs concerning the composition of mixed MSW relate especially to biowaste (in particular kitchen waste) and packaging waste (in particular plastic packaging). This indicates that the intensification of recycling, the landfill ban on organic waste and producer responsibility for packaging waste have particularly influenced the need for information about the composition of mixed MSW, as was assumed in advance. Respondents did not have information needs concerning the share of sticks and branches, other garden waste, clothes or other textiles in mixed MSW.

The respondents scored on an average 3.5 on a scale of 1 to 5 when they were asked to assess how well the classification system corresponds to their information needs about the composition of mixed MSW. Thus, the respondents were rather content with the classification system but also discovered some room for improvement. According to the responses, the classification of plastics requires most improvement. Several respondents suggested that plastics should be classified according to resin types. Particularly the share of polyvinyl chloride (PVC) in mixed MSW interested them. The purposes and aims of composition studies were also investigated in the survey. According to the responses, the determining the share of hazardous and biodegradable waste and waste materials suitable for recycling, i.e. material recovery, in mixed MSW were important for the composition study in addition to determing the waste fraction distribution. Several improvement proposals to the classification of fractions were formulated on the basis of the responses. These proposals are presented in Table 2. The results of the survey are presented in Supplementary material B.

Table 2
Improvement proposals to the classification of waste fractions.

	Improvement proposals
Biowaste	─ Kitchen waste should be classified more accurately at the third level ─ Waste categories 1.2.1 sticks and branches as well as 1.2.2 other garden waste should be removed from the third level
Plastic	─ Plastics should be classified according to resin types
Textiles, shoes and bags	─ Waste categories 8.2.1 clothes and 8.2.2 other textiles should be removed from the third level
Recyclable waste	─ Waste fractions should be classified on the basis of the recyclability, i.e. possibility for material recovery, of waste materials
Hazardous waste	─ All hazardous waste fractions should be included in one category at the first level

3.2 Results and experiences from the composition studies

The first composition study was conducted in a waste incineration plant in Riihimäki. Eight waste samples, each approximately 100 kg, were sorted into 38 categories according to the third level of classification in the study. The samples contained mainly mixed MSW from households. Additionally, the samples contained mixed MSW from public service producers, such as schools, but to a minor extent. As a result of the study, the average composition of the waste samples was determined (see Fig. 1 and Supplementary material C).

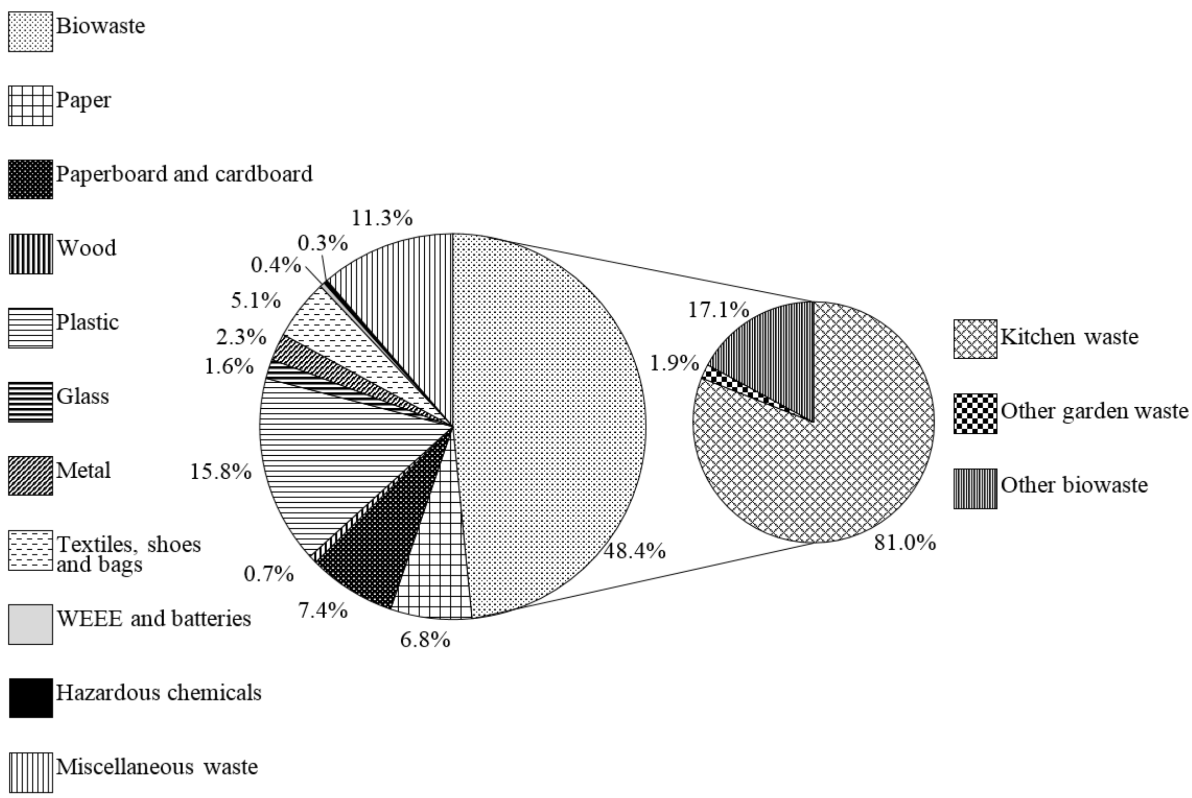

Fig. 1. The composition of mixed MSW and the composition of biowaste in the first composition study.

Kitchen waste was clearly the largest of the third level categories since its share was 39%, whereas the share of the second largest category, i.e. other biowaste, was 8%. However, kitchen waste is not classified further at the third level (see Table 1). It has been evaluated that the annual CO_2-equivalent emissions of food waste are more than 1% of the total annual greenhouse gas (GHG) emissions in Finland (Katajajuuri et al. 2014). In 2014, the waste management sector produced approximately 2% of the total GHG emissions in Finland (Statistics Finland, 2015d). Thus, from the viewpoint of the environmental impact of mixed MSW, it is important to know the share of avoidable food waste in mixed MSW. Because of this, the classification of kitchen waste was updated after the first composition study so that kitchen waste is classified to avoidable food waste and unavoidable food waste at the third level. Avoidable food waste can be defined as waste that could have been consumed (e.g. food leftovers, spoiled and dried food), while unavoidable food waste can be defined as waste that is not regarded as edible (e.g. coffee grounds, tea bags, vegetable and fruit peels, bones) (Bernstad Saraiva Schott and Andersson, 2015).

The second composition study was carried out in a municipal waste management centre in Turku. Altogether 22 samples, each approximately 100 kg, were sorted according to the third level of the updated classification system in the study. Thus, samples were sorted into 39 categories. As in the first composition study, the samples included mainly mixed MSW from households. To a minor extent, there was also mixed MSW from public service producers and private sector operators in the samples. The average composition of the waste samples was determined according to the proportions of the waste categories (see Fig. 2 and Supplementary material C). As a result of defining the classification of kitchen waste, it was found that 35% of kitchen waste was avoidable food waste. Bernstad Saraiva Schott and Andersson (2015) discovered that 35% of separately collected household food waste is avoidable food waste. Based on this, the composition of kitchen waste in mixed MSW is similar to the composition of separately collected food waste.

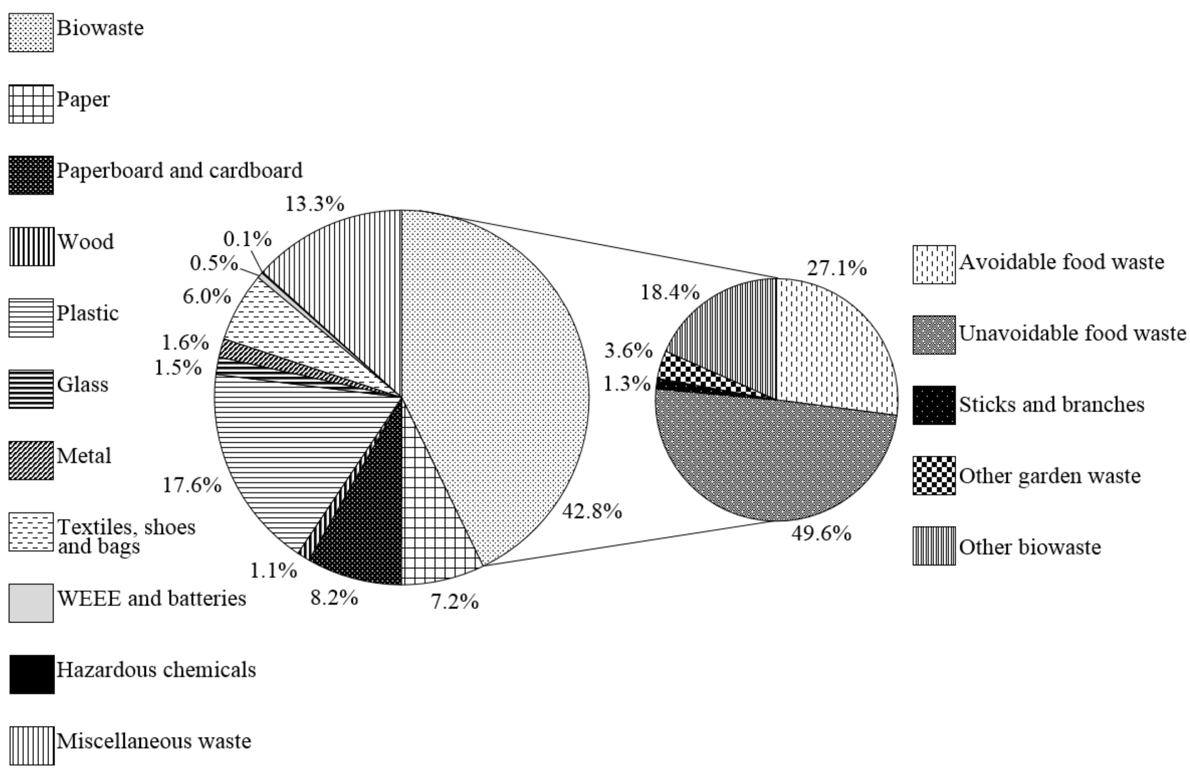

Fig. 2. The composition of mixed MSW and the composition of biowaste in the second composition study.

The composition of mixed MSW was rather similar in both studies. Biowaste, plastic and miscellaneous waste were the main fractions in mixed MSW in the studies. Even though the proportions of categories varied somewhat between the studies, the order of categories was the same in both studies, i.e. the share of biowaste was the largest, the share of plastic was the second largest, etc. The share of biowaste in mixed MSW was significantly larger than the average share of biowaste, i.e. approximately 36%, in Finnish mixed MSW in both studies. Otherwise, the results of the composition studies were relatively consistent with the average composition of mixed MSW in Finland. (Finnish Solid Waste Association, 2016.)

Table 3 presents the standard deviations, the coefficients of variation and the probability values from the Shapiro-Wilk test and the Mann-Whitney U test at the first level of classification. Based on the coefficients of variation, the proportions of wood, WEEE and batteries as well as hazardous chemicals varied relatively most in the composition studies. Respectively, the proportions of biowaste, plastic as well as paperboard and cardboard varied relatively least in the studies. According to the probability values from the Shapiro-Wilk test, the composition of mixed MSW was not completely normally distributed in either of the studies. All other first level categories apart from wood and hazardous chemicals were normally distributed in Riihimäki, whereas in Turku, only plastic, metal, textiles, shoes and bags, and miscellaneous waste were normally distributed due to higher variation in the composition of mixed MSW. Based on this, the higher number of samples did not decrease the variation in the composition data. The distributions of metal and hazardous chemicals varied significantly among the case areas according to the Mann-Whitney U test. Otherwise, the distributions of waste categories were rather similar regardless of the case area. Since case areas were not divided into non-overlapping strata, the influence of e.g. different building types and waste producers as well as socio-economic differences on the composition of mixed MSW cannot be investigated.

Table 3
Standard deviations (SD), coefficients of variation (CV) and probability values from the Shapiro-Wilk test and the Mann-Whitney U test at first level of classification.

Waste category	SD (%)		CV (-)		Shapiro-Wilk *p*-value[a]		Mann-Whitney U *p*-value[b]
	Riihimäki	Turku	Riihimäki	Turku	Riihimäki	Turku	
Biowaste	4.87	8.83	0.10	0.21	0.908	**0.004**	0.170
Paper	2.85	3.18	0.42	0.44	0.684	**0.048**	0.801
Paperboard and cardboard	0.73	2.29	0.10	0.28	0.164	**0.003**	0.344
Wood	0.66	1.37	0.99	1.20	**0.020**	**0.000**	0.565
Plastic	1.99	3.05	0.13	0.17	0.104	0.181	0.142
Glass	0.64	0.95	0.39	0.64	0.141	**0.013**	0.447
Metal	0.62	0.48	0.27	0.30	0.265	0.175	**0.018**
Textiles, shoes and bags	1.01	2.92	0.20	0.49	0.497	0.152	0.765
WEEE and batteries	0.21	0.48	0.53	1.05	0.918	**0.001**	0.597
Hazardous chemicals	0.33	0.12	1.03	1.05	**0.001**	**0.001**	**0.004**
Miscellaneous waste	5.40	4.45	0.48	0.33	0.121	0.579	0.219

[a] *p*-value < 0.05 indicates a non-normal distribution of data.
[b] *p*-value < 0.05 indicates a significant difference among case areas.

Both the European Commission (2004) and Sahimaa et al. (2015) recommend that confidence intervals should be determined for each waste category. The results of composition studies should be expressed on a 95% confidence level so that the relative confidence interval (i.e. the maximum allowance for a random sampling error) of the total results is below 10%. The relative confidence intervals of the predominant categories (i.e. biowaste; paper; paperboard and cardboard; plastic; glass; metal; textiles, shoes and bags; miscellaneous waste) should instead be below 20%. The relative confidence intervals can be determined by assuming that the composition data follows Student's t-distribution. (European Commission, 2004.) Since the composition data was not completely normally distributed in either of the studies, the relative confidence intervals of the total results cannot be determined correspondingly. However, confidence intervals can be determined for the normally distributed waste categories in the composition studies (Table 3). In Riihimäki, the confidence intervals of biowaste (11.5%), paperboard and cardboard (8.3%), plastic (11.0%) as well as textiles, shoes and bags (14.4%) were below 20%. Respectively, in Turku, the confidence intervals of plastic (7.4%), metal (13.7%) and miscellaneous waste (15.2%) were below 20%. Based on this, the normal distribution of the composition data should always be verified in the statistical analysis of the results and confidence intervals should be determined only for the normally distributed waste categories according to the guidelines of the European Commission (2004). Furthermore, the confidence intervals of individual waste categories can be much more informative than a confidence interval of the total results, particularly when the number of samples is lower than the recommended 35, due to certain waste categories (e.g. wood, hazardous chemicals, WEEE and batteries) which might not be normally distributed even in higher number of samples since they typically accumulate very irregularly in mixed MSW composition studies.

In both studies, sorting was considerably slower than initially estimated. In the method for Finnish mixed MSW composition studies, it is evaluated that sorting of a sample (100 kg) into 20-30 categories takes approximately eight man-hours (Toivonen and Sahimaa, 2014). Respectively, in the European Commission's method for solid waste composition studies, it is estimated that the sorting of 100 kg of waste takes six man-hours (European Commission, 2004). In the first study, the sorting of a sample took approximately 24 man-hours, whereas in the second study, the corresponding duration of sorting was 16 man-hours.

Sorting of waste containing several materials was one of the factors that slowed down the sorting. According to the method, different materials should be separated from each other if it is possible with reasonable effort. If separation is not possible, the waste item should be sorted according to its main material so that other materials' share is at the most 5% of the total mass of the waste. (Toivonen and Sahimaa, 2014.) This proved to be remarkably time-consuming. Edjabou et al. (2015) have discovered that separating food leftovers from food packaging has no considerable effect on the proportions of food waste and packaging materials. Additionally, according to Lebersorger and Schneider (2011), packed food waste should be sorted into the relevant food waste category together with its packaging in order to avoid a significant loss of information. Based on this, the necessity of such precise separation of different materials can be questioned at least for biowaste but also for all waste fractions. In order to keep the duration of a composition study reasonable, it would be important to identify the waste fractions that are worthwhile to separate precisely. Waste fractions that accumulate only a little in composition studies, i.e. wood, glass, metal, WEEE and batteries as well as hazardous chemicals, should at least be sorted precisely by separating different waste materials. As to other waste fractions, the necessity of such precise separation should be evaluated more closely in a separate study.

Additionally, the large share of biowaste in the waste samples had an effect on the duration of sorting. Due to the biowaste, the waste samples were wet and other waste fractions (e.g. plastic, paper, paperboard and cardboard) contained biowaste residues. Because of this, the identification of different waste fractions was challenging. The particle size of biowaste (i.a. fruit and vegetable peels) was small which further slowed down the sorting.

Planning proved to be an extremely important factor in composition studies. To facilitate sorting, sorting practices should be planned carefully in advance, particularly when samples are sorted according to the second or third level of classification. Based on the composition studies, certain fractions should be sorted stepwise. These fractions are paper, plastic, metal, and paperboard and cardboard. In the first study, also miscellaneous waste was sorted stepwise. However, it was not worthwhile because it complicated and slowed down the sorting. Thus, it is recommendable to sort miscellaneous waste and other fractions (i.e. biowaste; wood; glass; textiles, shoes and bags; WEEE and batteries; hazardous chemicals) directly according to the second or third level. In addition to the planning of sorting, also many other factors should be taken into account in the planning of composition studies. For instance, the work distribution of sampling and sorting as well as the training of sorters should be noticed in the planning phase of composition studies.

3.3 Updating of the classification system

The classification of biowaste was updated after the first composition study. Contrary to the assumption by Sahimaa et al. (2015), sorting kitchen waste into avoidable food waste and unavoidable food waste did not increase the workload of the composition study significantly. Since the share of biowaste in mixed MSW is high, as is the share of kitchen waste in biowaste, the information gained about the composition of kitchen waste provides significant additional information to the entire study. Thus, the further classification of kitchen waste is worthwhile.

The classification system was updated also in other ways (see Fig. 3). Of the development proposals presented in Table 2, the proposal concerning the recyclability of waste materials was taken into account in the updating of the method. The total amount of waste materials suitable for recycling could not be determined when the composition studies were carried out according to the method because both recyclable and non-recyclable waste materials were included in the same categories at the third level of classification. These categories were other non-packaging paper, and non-packaging paperboard and cardboard. Hence, the classification of paper as well as paperboard and cardboard was further defined.

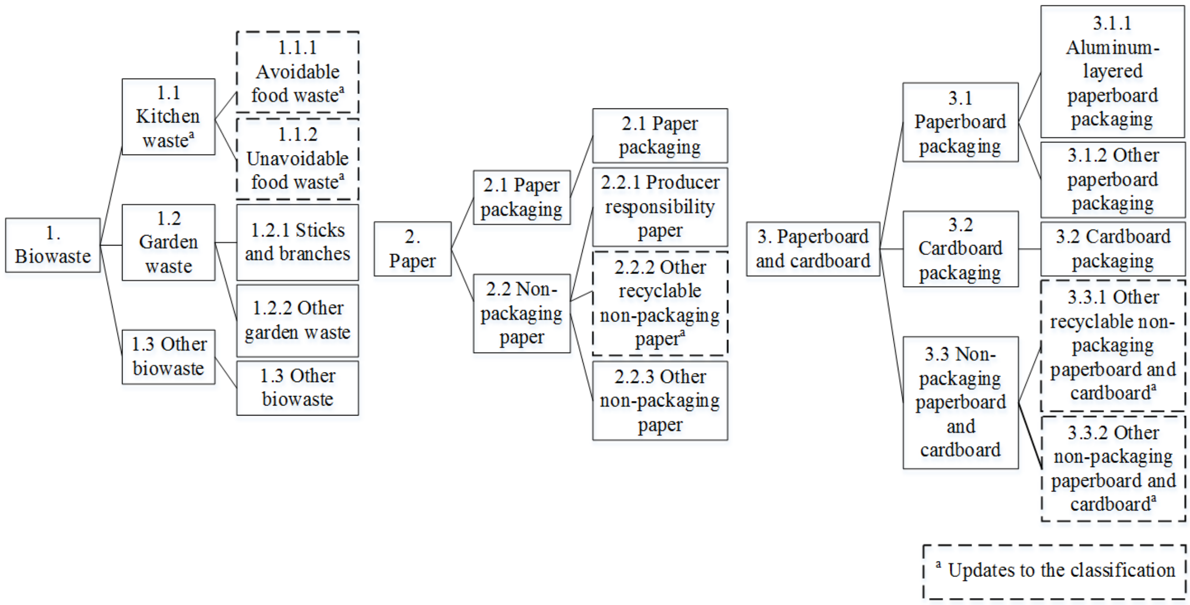

Fig. 3. Updating the classification of waste fractions.

The updating of the classification system inevitably affects the statistical reliability of the results since the number of categories increases at the third level of classification. Thus, more samples are required in order to reach the same level of accuracy in the third level compared to the initial classification system. However, since the share of paper as well as paperboard and cardboard is rather high in mixed MSW, approximately 17% (Finnish Solid Waste Association, 2016), it is important to know the recyclable share of these fractions in mixed MSW. On this account, the more detailed classification of these fractions is worthwhile even though the statistical reliability of the results decreases slightly at the third level of classification.

The classification of plastic was not updated even though, according to the responses of the survey, it was most in need of improvement. Sorted plastics from both composition studies were sorted further into 10 categories based on resin types in two separate studies which were carried out after the composition studies. Sorting based on resin types proved to be extremely challenging and time-consuming. Amongst other things, impurities as well as the lack of resin codes and variation in the codes' positions complicated the identification of different plastics. Since sorting proved to be so time-consuming, the classification of plastic was not updated in order to keep the duration of sorting in reasonable limits. The respondents of the survey were particularly interested in the share of PVC in mixed MSW. The share of PVC in sorted plastics was minor. In both studies, the share of PVC in mixed MSW was less than 1%. (Poliakova, 2015.) Additionally, the identification of PVC in composition studies is difficult since PVC cannot always by recognised visually (Sahimaa et al., 2015). Therefore, a separate category for PVC was not added to the classification.

The classification of hazardous waste was not updated, either, even though the responses to the surveys conducted in this study and by Sahimaa et al. (2015) suggest that the share of hazardous waste in mixed MSW interests both municipal and private operators in the waste sector. However, there is no separate category for hazardous waste at the first level of the classification. If all hazardous waste fractions were included in the same first level category, it would distort other categories' proportions because hazardous waste consists of different materials. For instance, treated wood can be classified into hazardous waste even though according to its material it should be classified as wood. Therefore, to maintain the material based classification of fractions at the first level of the classification system, the classification of hazardous waste was not updated.

No categories were removed from the classification system even though two improvement proposals presented in Table 2 concerned the removal of certain categories from the third level of classification. Because the performer of the composition study can choose the level of classification for each category according to the need for information about mixed MSW, there is no need to remove any categories from the classification. Table 4 presents the updated classification system as well as categories for hazardous and recyclable waste. Supplemented guidelines on which waste fractions are included in each category are presented in Supplementary material D.

Table 4
The updated classification of waste fractions.

Level 1	Level 2 & 3	Hazardous waste	Recyclable
1. Biowaste	1.1.1 Avoidable food waste	No	Yes
	1.1.2 Unavoidable food waste	No	Yes
	1.2.1 Sticks and branches	No	Yes
	1.2.2 Other garden waste	No	Yes
	1.3 Other biowaste	No	Yes
2. Paper	2.1 Paper packaging	No	Yes
	2.2.1 Producer responsibility paper	No	Yes
	2.2.2 Other recyclable non-packaging paper	No	Yes
	2.2.3 Other non-packaging paper	No	No
3. Paperboard and cardboard	3.1.1 Aluminium-layered paperboard packaging	No	Yes
	3.1.2 Other paperboard packaging	No	Yes
	3.2 Cardboard packaging	No	Yes
	3.3.1 Other recyclable non-packaging paperboard and cardboard	No	Yes
	3.3.2 Other non-packaging paperboard and cardboard	No	No
4. Wood	4.1 Wood packaging	No	Yes
	4.2 Treated wood	Yes	No
	4.3.1 Construction and demolition wood	No	No
	4.3.2 Other untreated non-packaging wood	No	No
5. Plastic	5.1.1 Dense plastic packaging	No	Yes
	5.1.2 Plastic film packaging	No	Yes
	5.2.1 Non-packaging dense plastic	No	Yes
	5.2.2 Non-packaging plastic film	No	Yes
6. Glass	6.1 Glass packaging	No	Yes
	6.2 Non-packaging glass	No	No
7. Metal	7.1.1 Aluminium packaging	No	Yes
	7.1.2 Other metal packaging	No	Yes
	7.2 Non-packaging metal	No	Yes
8. Textiles, shoes and bags	8.1 Shoes and bags	No	No
	8.2.1 Clothes	No	Yes
	8.2.2 Other textiles	No	Yes
9. WEEE and batteries	9.1.1 Fluorescent tubes, low energy and LED light bulbs	Yes	Yes
	9.1.2 Other WEEE	No	Yes
	9.2 Small batteries	Yes	Yes
	9.3 Automotive accumulators	Yes	Yes
10. Hazardous chemicals	10.1 Medicines	Yes	No
	10.2 Other hazardous chemicals	Yes	No
	11.1 Miscellaneous packaging	No	No

11. Miscellaneous waste	11.2 Diapers and sanitary protectors	No	No
	11.3.1 Other combustible waste	No	No
	11.3.2 Rubble	No	No
	11.3.3 Other non-combustible waste	No	No

4 Conclusions

The primary objective of the study was to update a method for Finnish mixed MSW composition studies in such a way that it corresponds to the need for information about the composition of mixed MSW in Finland and still works in practice. The method was updated based on the results of a survey and two composition studies. The updating of the method focused on the classification of waste fractions. The classification of biowaste, paper, and paperboard and cardboard was updated to meet information needs. The classification of kitchen waste was further classified to avoidable and unavoidable food waste at the third level of classification. Additionally, categories for recyclable non-packaging paper as well as paperboard and cardboard were added to the third level of classification. The updated classification of waste fractions provides important information from the perspective of environmental impacts of mixed MSW and enables the determination of the total share of waste materials suitable for recycling in mixed MSW in composition studies.

Different methods for mixed MSW composition studies have been introduced and reviewed in several previous studies. However, the functionality of composition study methods has not been assessed previously. In the composition studies, sorting proved to be considerably slower than initially estimated. This should be particularly taken into account in the planning of forthcoming composition studies. Since the composition data was not normally distributed in either of the studies, the confidence intervals of the results could not be determined according to recommendations. It was concluded that individual waste categories' confidence intervals are more informative and useful than the confidence interval of the total results, particularly when the number of samples is rather low, as in this study. The updated classification system and sorting guidelines of the method as well as the information gained from the composition studies are important in ensuring that the method will be adopted widely in Finland.

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Appendix A. Supplementary material

The supplementary material contains the questions and results of the survey, results from the composition studies and examples of waste fractions included in different categories of the updated classification system. Supplementary data associated with this article can be found, in the online version, at <insert link here>.

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