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FACTORS AFFECTING THE REPRODUCIBILITY OF WASTE SAMPLING AND COMPOSITION ANALYSES

Emilia den Boer[1*], Andrzej Jędrczak[2], Jan den Boer[3], Tadeusz Butrymowicz[2]

[1] *Wrocław University of Science and Technology, Faculty of Environmental Engineering, Section of Waste Technology and Land Remediation, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław Poland*
[2] *University of Zielona Góra, Institute of Environmental Engineering, ul. Szafrana 15, 65-516 Zielona Góra, Poland*
[3] *Wrocław University of Environmental and Life Sciences, Institute of Agricultural Engineering, Division of Low Emission Energy Sources and Waste Management, ul. Chełmońskiego 37a, 51-630 Wrocław, Poland*

Abstract

This paper summarises the main findings regarding the precision of municipal residual waste sampling and composition analyses attended by six laboratories. The purpose of the performed analyses was to determine factors affecting reproducibility of the procedure, which is supposed to become part of the new Polish waste analysis standard, in comparison to the previous standard. A sample size of 100 kg is proposed as a required sample size in the new norm, while 5 kg samples were used in the previous norm. The sorting samples were derived from a batch of waste delivered by collection vehicles. In case of the 100 kg sample, the average coefficient of variation for the 11 main material fractions amounted to 44%, while for the 5 kg sample it was 72%. In case of 100 kg samples, 10 repetitions would provide statistically valid contents of the major material fractions, even if sorting is done be different teams. Sorting into 36 material sub-fractions provided very high variability of results between the labs. The proposed methodology provides a good basis for a waste sampling standard, however, due to the high rate of human involvement there is still some room for subjectivity. Among factors affecting the reproducibility of results the most important are: the sorting mechanism (including the shape of slots and the effectiveness of sieving) and interpretation of the individual material categories. A more accurate definition of those could improve the reproducibility of the procedure.

Key words: reproducibility, residual waste, sampling, sorting

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1. Introduction

Data about waste composition is a prerequisite of a well based waste management strategy and for designing waste treatment facilities. Also municipalities in Europe require reliable information on the composition of municipal waste to monitor progress towards recycling and recovery targets. In recent years many municipal waste compositional surveys have been undertaken through a number of investment projects and research programmes (Burnley, 2007; Cutaia et al., 2016; Defra, 2008; Denafas et al., 2014; Edjabou et al., 2015; Eisted and Christensen, 2011; Hryb, 2015; Riber et al., 2009; Senzige et al., 2014; Vuijć et al., 2010). Methodologies applied in these studies vary between each other and depend on the purpose of waste sorting analyses.

In Poland, according to the official norm (PN-93/Z15006 (1993)), a 5 kg sample for the sorting analyses is separated out of the batch of 500 kg residual waste. The formation of the final 5 kg sample is done by merging together not less than 30 unit samples (of total volume greater than 0.25 m^3), which

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[*] Author to whom all correspondence should be addressed: e-mail: emilia.denboer@pwr.edu.pl; Phone: +48 790757706; Fax: +48 71 328 29 80

are picked from the batch. Only the 5 kg "representative" sample undergoes the sorting procedure. Sorting is done according to PN-93/Z-15006 norm. In the time 2007-2012 300 out of 391 (75%) waste sorting analyses were done according to PN-93/Z-15006 norm (Jędrczak, 2013). In fact, a 5 kg sample size is far too small to provide representative results. Moreover, the analyses are often limited to one or few sorting samples only, which implies very low credibility of the final result (Jędrczak, 2013). Thus, development of a new national waste sorting norm has started in order to replace the outdated one. In the proposed Polish norm three options of sampling are foreseen, depending on the purpose of the sorting study:

- directly from the containers in which waste is collected, when the aim of the research is to provide information within the framework of: general monitoring of the quantity and quality of waste, development of waste management plans for a specific area etc.
- from the vehicles delivering waste to the waste treatment plant or transfer station, when the aim of the research is to provide detailed information for selecting waste treatment technology or the design of waste treatment installation for a given region.
- from the technological line of the treatment plant, e.g. from conveyors feeding drum sieve and / or oversize or undersize fraction from the screen. Based on the results of these studies the effectiveness of the installation can be assessed.

In this paper we focus only on the second sampling option. Vehicle load sampling has been carried out by Chang and Davila (2008), Petersen (2004), Sharma and McBean (2009) and Wagland et al. (2011). The sorting sample size proposed by various studies varies from 91 kg to 300 kg (Dahlén and Lagerkvist, 2008). Since splitting the mother sample can introduce some bias, Edjabou et al. (2015) sorted the whole load of a truck. This is, however, much more labour intensive and thus more expensive. In the proposed norm a sorting subsample size of 100 kg was chosen.

In the current paper results of sorting analyses of the same residual waste batch (general sample), performed by six independent laboratories, who routinely perform waste sorting analyses, are presented. Each participating laboratory followed the same sampling and sorting protocol, which is expected to become part of a new national norm for waste analyses in Poland.

A well designed norm should minimise any misinterpretations by the sorting teams (leading to systematic errors) and allow to provide the waste composition estimate with a required accuracy. "Accuracy" is used to describe the closeness of a measurement to the true value and it consists of *trueness* (proximity of measurement results to the true value) and *precision* (repeatability or reproducibility of the measurement) (ISO 5725-1). Accuracy involves a component of systematic error (affecting the trueness of a measurement) and a component of random error (affecting the precision of the measurement) (Rabinovich, 2005; Williams, 2016). Precision is usually expressed in terms of imprecision, e.g. standard deviation, variance, or coefficient of variation of the test results (Chesher, 2008). Repeatability and reproducibility of the measurement express the variability of results measured, accordingly within and between different laboratories (Di Maria and Miscale, 2014; Di Maria et al., 2015; Scaglia et al., 2011a; Scaglia et al., 2011b). Repeatability is the precision under the 'same' conditions, meaning that independent test results are obtained with the same method, by the same operator, using the same equipment, and within short period of time. Reproducibility is the precision under changing conditions, meaning that independent test results are obtained with the same method, with different operators, using different (or recalibrated) equipment (COM 2002/657/EC). Repeatability leads to an estimate of the minimum value of precision, while reproducibility provides an estimate of the maximum value of precision (Scaglia et al., 2011a; Scaglia et al., 2011b).

The focus of this study is laid on identifying sources of errors affecting the reproducibility of results when sampling and sorting analyses are performed by different laboratories. The teams used their own equipment and performed analyses according to the previous and the newly drafted standard.

Results of waste sorting analyses provide an estimate of the actual waste composition with a given accuracy. Sampling error is the error caused by observing a sample instead of the whole population. It is used to form a confidence interval (bandwidth) for the result. The maximum allowance for random sampling error describes the bandwidth of a confidence interval at a certain confidence level. For waste sorting analyses it was recommended that as a measure of statistical accuracy of results a relative confidence interval shall be employed with a confidence level of 95% and the relative interval for the predominant categories organic, paper, glass, plastic, metal and fines of 20% (European Commission 2004). This is a necessary parameter to calculate the number of sorting samples needed for waste sorting analyses. Another goal of this study was to estimate the number of sorting samples needed to provide results with recommended maximum allowed sampling error and confidence level for both 5 kg and 100 kg samples.

2. Material and methods

2.1. Sampling and sorting procedures

The residual waste for the sorting analyses described in this paper was collected from the vehicles delivering residual waste from the town of Zielona Góra to the Waste Treatment Plant in Racula. The waste batch (general sample) was prepared on the day before the sorting analyses were done. Waste was discharged directly from the vehicle delivering waste (about 10,000 kg in the form of an elongated flat pile with a height of approx. 0.5 m). The participating laboratories formed their own two sorting samples (samples B1 and B2), using prescribed sampling procedure and performed sorting analyses:

Sample B1 - each participant formed it by marching together 10 unit samples of 10 kg evenly distributed throughout the pile of waste batch. The 100 kg sample was sieved by each participant into particle sizes of >100 mm, 80-100 mm, 40-80 mm, 20-40 mm, 10-20 mm and <10 mm. Size fractions were collected and, except for fine fractions (<20 mm), separated into specified material categories. Fine fractions (<20 mm) include sand, dust, ash, fine organic particles, seeds, etc. Samples 20-40 and 40–80 mm were sorted into 11 main material categories, while fractions 80–100 and >100 mm were separated into 36 sub-categories (see Fig. 1). Each time after sorting, the fine fraction remaining on the sorting table was added to the fraction of 10-20 mm. Each material fraction was weighted with an accuracy of 10 g. Thus, this task allowed to assess the reproducibility of sampling, sieving and sorting to 11 main and 36-sub-categories (listed in Table 1) by the six teams of a 100 kg sample.

Sample B2 was formed according to the branch norm (BN-87/9103-03, 1987). Waste samples of 5 kg were selected by each participant by the procedure of merging together not less than 30 unit samples (with the volume of 0.25 m^3) from the waste batch, followed by a coning and quartering procedure**.** The 5 kg sorting sample was screened to particle size fractions of <10 mm and >10 mm. After weighting (with an accuracy of 0.5 g), the fraction larger than 10 mm was sorted to 11 main material categories, the same ones as sample B1, to allow comparability. Fine residues of the sorting were added to the fraction of <10 mm. Thus, this task allowed to test comparability of sampling and sorting by the six laboratories a sample of 5 kg, according to the existing norm.

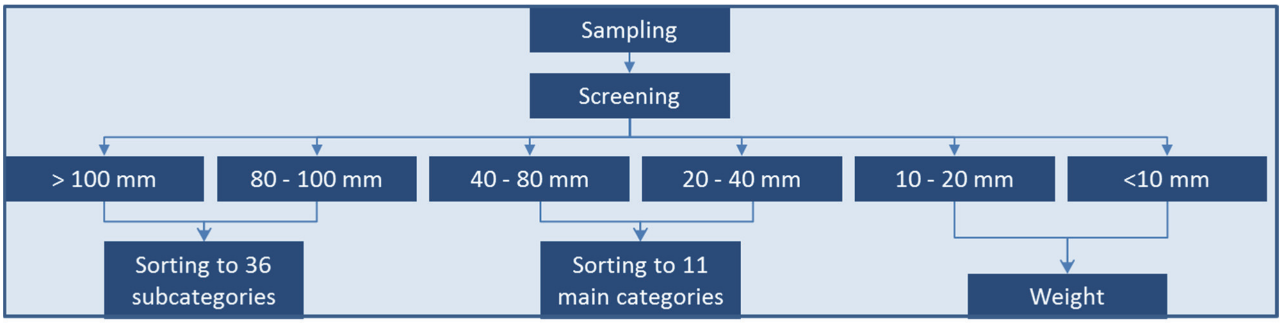

Fig. 1. Sampling schedule according to modified SWA Tool methodology

Table 1. Main material categories and sub-categories, according to modified SWA Tool methodology

Nr.	***Main categories***	***Sub-categories***	***Typical waste items***
1.	Bio-degradable organics	Kitchen/Canteen waste	Bread; coffee grinds; cooked or uncooked food items, fruit and vegetables; meat and fish; pet foods; tea bags,; unused food with packaging if it cannot easily be separated from leftovers of food, such as a jar of honey, a package with the residues of soft cheese
		Garden/Park waste	Flowers; fruit and vegetable garden waste; grass cuttings; hedge trimmings; leaves; pruning; tree branches; weeds
		Other biodegradation waste	Animal remains; bones; faeces; oils and food fats
2.	Wood	Wood packaging	Bottle corks; cork packaging, untreated timber pallets
		Untreated wood	Fragments of untreated beams, wooden fences (not painted, not lacquered), pieces of untreated timber
		Treated wood	Pieces of chipboard, MDF, plywood, fragments of fences, furniture, items of treated timber
3.	Paper and cardboard	Paper/card packaging	Cardboard packaging, corrugated cardboard packaging (bulk and small); fast-food packaging; eggs cartons; paper bags; packaging of: handkerchiefs, toys, washing powder; wrapping paper, food packaging; animals feed packaging, etc.
		Newspapers	Newspapers, advertising leaflets, other newsprint
		Non-biodegradable paper	Magazines, catalogues, advertising, brochures with glossy paper, photographs, wallpaper
		Other Paper/card – non packaging	Greeting cards; books; notebooks; computer printouts; envelopes; invoices; paper towels; loose sheets; non glossy brochures and office paper; posters; phone books; tickets; handkerchiefs; toilet paper; paper sheets
4.	Plastics	Plastic film –packaging	Compost bags; plastic containers (for biscuits, chips, frozen foods); food and animal feed bags; packaging film, packaging bags
		Plastic film –non packaging	Garden foils; non packaging bags; shopping bags, tarpaulins; garbage bags

		Plastic bottles/jars	Bottles and plastic jars of: soft drinks, juices, water, edible oil; detergents, shampoos and other chemical products used in housekeeping, gardening, automotive (PE); other packaging intended for contact with food (PET).
		Other packaging plastics	Tubes of all products; plastic egg packages; packaging of: ice cream, yoghurts, margarine; lids; plastic caps; plastic bottles of deodorants (roll-on); plastic caps
		Non packaging plastics	Credit cards; cash machines; CDs; cassettes; video tapes; shaving razors; linoleum pieces; plastic garden hoses, etc., plastic garden equipment; plastic accessories for housekeeping and cars; pens; lighters; pots; frames; glasses; shoes; plastic toys; rulers; bowls, lids with covers
5.	Glass	Glass packaging - clear	Jars and bottles of beverages (wine, milk); food (coffee, jams, sauces, meals for children); medicines
		Glass packaging - brown	Jars and bottles of beverages (beer), food, medicines
		Glass packaging - other	Jars and bottles of beverages (beer, red wine), food, medicine
		Miscellaneous non packaging glass	Glasses; glass; mirrors; lightning bulbs; cooking utensils; glasses; mixed glass cullet; screens of televisions and computers (only if previously separated)
6.	Textiles	Textile packaging	Some types of bags, such as for potatoes
		Clothing	Socks, trousers, jackets, tights, underwear, hats, gloves etc.
		Non clothing textiles	Wool; blankets; carpets; handkerchiefs; textile pieces of furniture; wipers, tetra diapers, rags, threads, towels
7.	Metals	Ferrous packaging	Cans of foodstuffs, beverages, food for animals, fish; sweets; lids from jars; aerosols (deodorants, perfumes, varnishes, etc.)
		Non-ferrous packaging	Cans of soft drinks and beer; pieces of aluminum foil; packaging of food, cosmetics; bottle caps
		Miscellaneous ferrous	Locks; nails; knives; paper clips; construction elements; screws; tools; metal shelves; radiators; pots and pans; hangers; etc.
		Miscellaneous non ferrous	Other aluminium and metal waste; copper wires
8.	Hazardous waste	Batteries/Accumulators	All types of batteries and accumulators
		Miscellaneous hazardous waste	Remains of paints; inks; fluorescent lamps; aerosols and packaging of these agents; medicines; detergents; used oil and oil filters; chemicals; inks and toners
9.	Composites	Composite/complex packaging	Cartons covered with aluminium foil, milk cartons, juices (such as tetrapacks)
		Composite/Complex non packag.	Automotive parts, motors, parts of household appliances, shoes, sandals
		Mixed WEEE	Appliances, including: fans, watches, dryers, coffee makers, knives, toothbrushes, mechanical toys, game consoles, hardware, cell phones
10.	Inerts	Soil and stones	Pebbles, bricks, gravel, stones, soil
		Miscellaneous inert	Ceramics; pots; clay, floor / wall tiles; vases
11.	Other categories	Nappies	Nappies
		Health care/hygiene wastes	Bandages; swabs; syringes; patches
		Miscellaneous categories	All materials that cannot be qualified to the aforementioned category

2.2. Tools

The particle size composition was determined by sieving waste with respective manual or partly automated sets of sieves. The most common were manual sieves (see Fig. 2a and 2b), used one by one. One laboratory used a vibrating sorting machine (see Fig. 2c), where the sample was fed through a column with a cascade of sieves. Sieves with square slots were used by 4 laboratories, while 2 labs (lab 2 and lab 3) used sieves with circular slots. In all cases the diameter of circular slots was the same as the side of square slots. The material composition was determined by a manual sorting procedure (Fig. 2d).

2.3. Data evaluation

The results from all participants have been analysed using a standard statistical approach. Grubbs' test was used to eliminate outlier values. The results include: the mean values of the original data obtained by the different laboratories, standard deviation (SD) and coefficient of variation (CV). The calculation of the mean, SD and CV was performed after rejecting the outlier values.

Number of samples needed to obtain the required level of accuracy of the analyses was determined based on the maximum allowance of the random sampling error of the sample mean, according to Eq. (1) (European Commission, 2004):

$$n = \left(\frac{t_{\alpha,n-1} \cdot CV(x_i)}{e'} \right)^2 \tag{1}$$

where: $t_{\alpha,n-1}$ confidence coefficient of the t-distribution for the demanded confidence level (95%); $CV(x_i)$ coefficient of variation of the population; e' – the demanded accuracy (random sampling error), here 20%, as was recommended by the SWA-Tool methodology (European Commission, 2004).

(a) (b)

(c) (d)

Fig. 2. Sorting by different teams: (a) represents manual sieving procedure, (b) - typical manual sieves, (c) - vibrating sorting machine, (d) - manual determination of material composition

3. Results and discussion

3.1. Sample B-1

Results of grain size distributions reported by various laboratories are presented in Fig. 3, along with average values. Error bars represent the SD values. The dominating fraction was the coarse fraction (>100 mm), with the total share of 27.9%, followed by fraction 40-80 mm. The shares of fraction <10 mm and 10-20 mm were smaller. The maximum CV was determined for fraction 10-20 mm and amounted to 33%. The results did not confirm the expectation that the teams using sieves with circular slots (labs 2 and 3) would deliver a different distribution from the ones using sieves with square slots. In general however, the difference in square and circular slots is a source of bias, which can also influence the distribution of materials in the size fractions.

The surface of a square with the given side size is 27.4% larger than of the circle with the same diameter. The length of the diagonal is 41.4% larger than the diameter. However, taking into account the different shapes, the maximum effective difference for sieving should not exceed 15%-20%. Moreover, there could be some influence of the sieving mechanism. All teams used flat screens, except for Lab 1, which used a rotating drum. The shares of fractions <10 mm and 10-20 mm of Lab 1 were higher than the average. It may be attributed to the higher separation efficiency of the rotating drum than of vibrating sieves. The norm neither defines the shape of slots, nor the sieving mechanism. Especially, the latter seems to influence the final result and should be taken in consideration when analysing the final results. In any case, standardising the sieve would surely increase the measurement precision.

The share of fraction >100 mm in the current study was smaller than the respective yearly averages for residual waste in other cities, e.g. 41.1% in Warsaw (den Boer et al., 2012) and 41.5% in Wroclaw (den Boer and Szpadt, 2012). In contrast, the share of fraction <10 mm was higher than the respective values for the other cities – 4.8% for Warsaw (den Boer et al., 2012) and 4.6% for Wroclaw (den Boer and Szpadt, 2012). This may be explained by higher separate collection rates of recyclables, and thus lower share of the largest size fraction in the residual waste currently, in comparison to the older data from other cities. Fig. 4 shows the material composition of samples B1 provided by the laboratories as well as the calculated average value, with SD values. The material composition reported in Fig. 4 is actually a summary of material composition of each size fraction. The variability is in this case significantly higher than for the grain size composition. The average CV for all fractions amounts to 44%. The highest CV-values were determined for wood (117%), hazardous waste (90%), metals (73%), composites (39%) and biodegradable organics (36%).

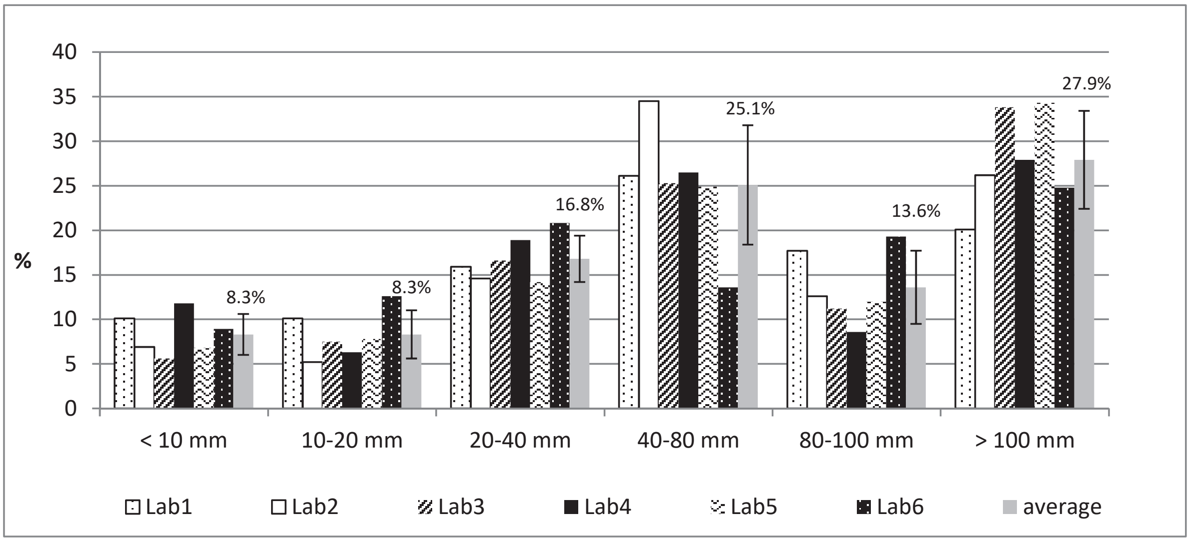

Fig. 3. Grain size composition, sample B1 [mass %]

It is surprising that in case of biodegradable organics, despite a high share of this fraction in waste, there was high variability of results obtained. This could be partly explained by a varying sorting depth. The norm specifies as one of the components this category the “unused food with packaging, if it cannot be easily separated of food leftovers, e.g. a jar of honey, packaging with leftovers of soft cheese.” This definition leaves room for different interpretations of what can be easily separated or not. This may cause variation in the final result, especially that the share of packed food is quite significant. Edjabou et al. (2015) found out that 27% of total food waste consisted of “packed food” waste (12% of the total residual waste). “Composite” and “other waste” are another two categories, which are also not easily definable and thus may lead to some confusion in the sorting. Generally, the content of biodegradable organics determined within the study (15.6%) is low compared to other data from Poland, even if the whole fraction 10-20 mm was also accounted for as organics.

In various analyses performed in 2011 the average share of organics was 27.9% (based on 30-100 kg samples), (Jędrczak, 2013), in Wrocław it amounted to 41.7% (den Boer and Szpadt, 2012) and in Warsaw biodegradable kitchen waste constituted 40.9% (den Boer et al., 2012). The low content determined within the current study might be due to the compaction of waste in the truck. The compaction causes disintegration of the soft food leftovers, which may be not recognisable anymore or even lost as leachate. For example, Danish waste characterization studies (such as Edjabou et al., 2015; Eisted and Christensen, 2011; Riber et al., 2009) avoid sieving of the waste sample in different particle sizes for the same reason as compaction, that is because this operation will itself affect the characteristics of different waste fractions, especially biodegradable organic materials. This should be kept in mind when interpreting the results of the sorting analyses and designing the sorting procedures. Surely when the intention of the analyses is to obtain data about the composition of waste generated, sampling directly from containers is more suitable. In this case sieving should also be avoided. Sampling after waste compaction in collection truck provides information suitable for waste treatment plant operator. In this state waste is delivered for further processing. Therefore, sampling in this way was considered as one option under the development of the Polish norm.

In the following the material composition of the examined sub-fractions is presented. Fig. 5 shows the material composition of fraction 20-40 mm. This fraction is basically dominated by the biodegradable organics (kitchen and garden waste), constituting on average 54.0% of the total mass. The other major contributors are inerts (15.3%), paper (15.2%) and glass (7.0%). All other fractions contribute individually less than 2%. From Fig. 5 it can be seen that all values for the main fractions kitchen and garden waste, paper and glass the CV values are relatively low (30%, 27% and 24%). However, for the other fractions the CV is very high –153% for the wood, 199% for inerts, 172% for textiles, 139% for other categories and 134.9% for hazardous waste. The average CV for all materials in this fraction is 84%.

Fig. 6 shows analogical values for the fraction 40-80 mm. The outlier excluded with help of the Grubb’s text included the textiles category (lab 6). This fraction is not very much dominated by any one of the materials. Paper share was highest (22.2%), followed by glass (17.7%), biodegradable organics (15.7%), inerts (14.8) and plastics (12.0%). The variability of data provided by individual laboratories is high. The highest CV is again observed for textiles (126%), hazardous waste (113%), other categories (94%), wood (91%) and glass (67%). The average CV for all materials in fraction 40-80 mm amounts to 60%.

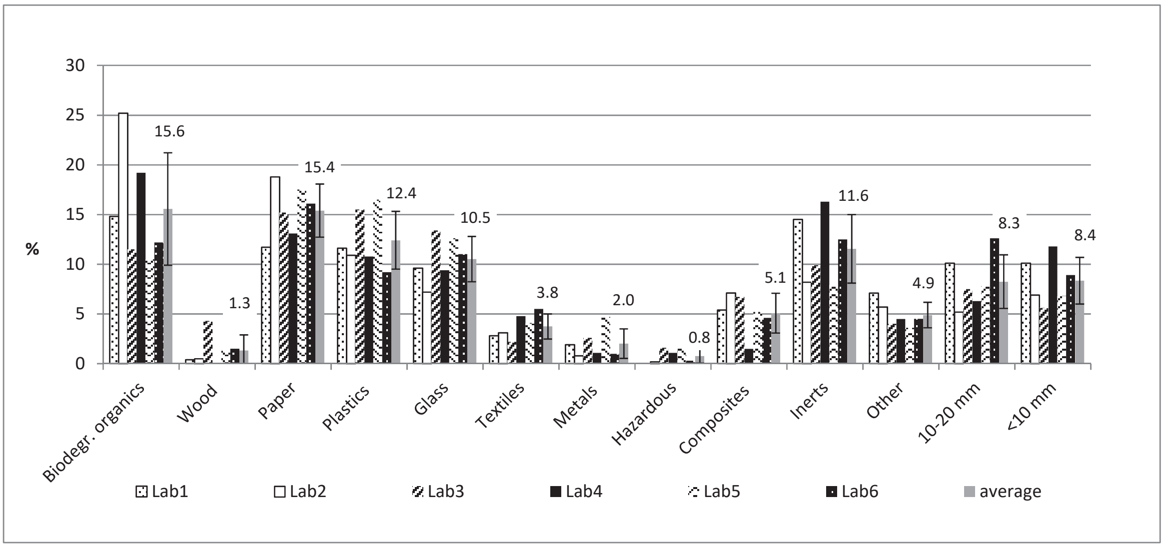

Fig. 4. Material composition of waste, sample B1 [mass %]

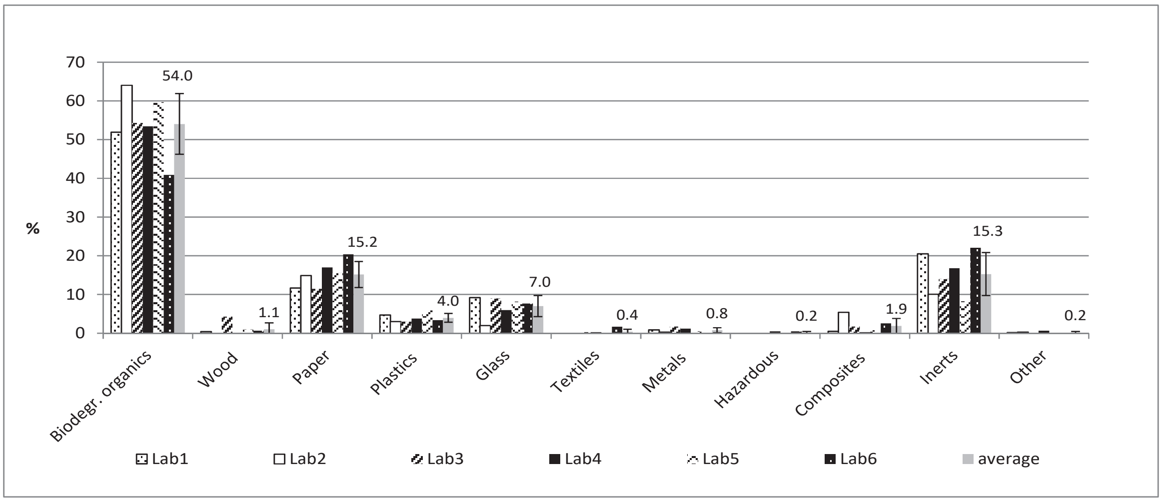

Fig. 5. Material composition of fraction 20-40 mm, sample B1 [mass %]

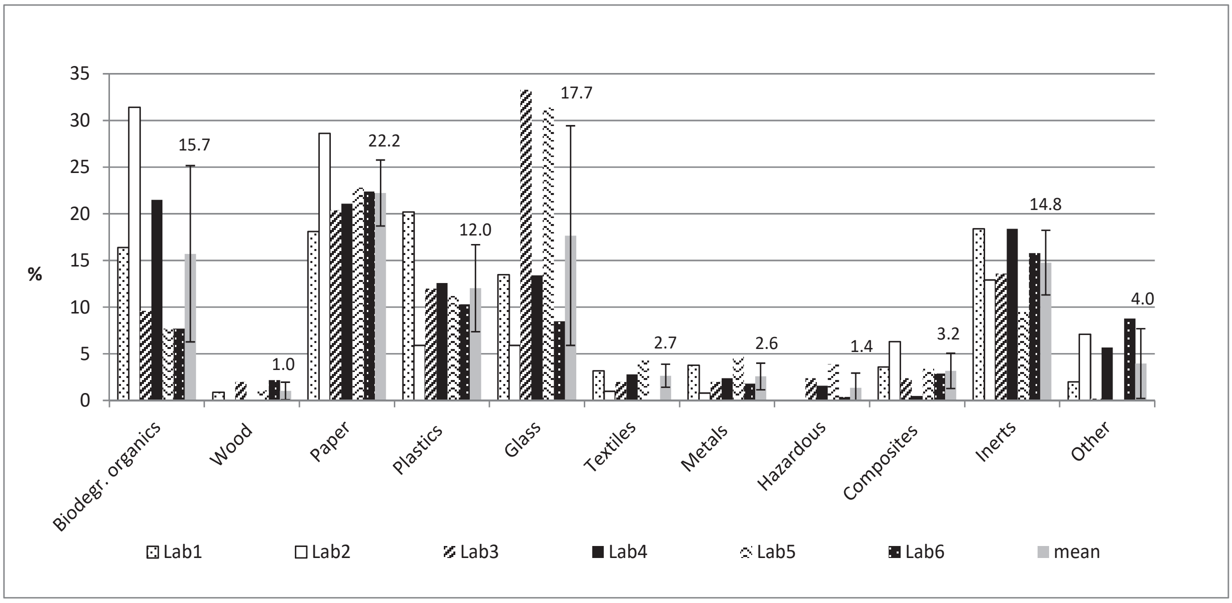

Fig. 6. Material composition of fraction 40-80 mm, sample B1 [mass %]

Table 2 presents the results of the detailed composition of fractions 80-100 mm and >100 mm. The data results from more detailed analyses in which 35 materials have been identified. The outliers excluded with help of the Grubb's test included garden/park waste (lab 6) and soil and stones (lab 4) in fraction 80-100 mm and treated wood >100 mm (lab 3). In the fraction 80-100 mm the dominating subcategories are nappies (15.3%), followed by glass packaging – clear (9.6%). In case of fraction >100 mm the dominating material are miscellaneous inert materials (10.4%) and non-packaging plastics (7.1%). It can be seen that the variability of this data is very significant. In Figs. 7 and 8 the results of individual laboratories only for fractions constituting at least 4% are presented, along with SD values. Average CV for fractions constituting at least 4% amounts to 67% and for all fractions 86%. For the categories with lower content a significantly higher number of sorting samples will be needed to provide results with the demanded accuracy.

3.2. Sample B-2

The results for the material composition of sample B2 (5 kg mass) are presented in Fig. 9. In this case there was one outlier detected – wood (lab 4), which was eliminated from a further assessment. The dominating material is biodegradable organics with a share of 21.4%, followed by plastics (19.1%), paper (15.4%) and fraction <10 mm (12.7%). The data reported by individual laboratories shows very high variability, significantly higher than for the samples B1. The variation coefficient of wood amounts to 189%, followed by textiles (140%), other categories (96%), fine fraction <10 mm (72%) and inert waste (71%). The average CV of all the materials amounts to 72%.

Table 2. Detailed material composition of the fractions 80-100 mm and >100 mm [mass %]

Main categories	***Sub-categories***	***Fraction 80-100 mm***		***Fraction >100 mm***	
		Average content [%]	***CV [%]***	***Average content [%]***	***CV [%]***
Biodegradable organics	Kitchen/Canteen waste	5.4	109	4.0	120
	Garden/Park waste	0.2	91	0.8	126
	Other biodegr. waste	0.3	174	0.2	155
Wood	Wood packaging	0.0	0	0.4	174
	Untreated wood	0.2	245	0.9	163
	Treated wood	0.4	174	0.5	189
Paper	Paper/card packaging	4.3	63	6.4	59
	Newspapers	2.8	85	4.0	46
	Non-biodegradable paper	0.3	93	3.1	94
	Other Paper/card – non packaging	6.5	76	5.2	57
Plastics	Plastic film –packaging	4.2	38	3.7	17
	Plastic film –non packaging	6.9	37	7.1	21
	Plastic bottles/jars	6.8	37	5.0	47
	Other packaging plastics	3.6	110	2.0	88
	Non packaging plastics	1.9	114	2.4	57
Glass	Glass packaging - clear	9.6	78	6.0	54
	Glass packaging - brown	3.3	180	1.8	103
	Glass packaging - other	1.4	139	3.4	108
	Miscellaneous non packaging glass	0.2	245	0.0	0
Textiles	Textile packaging	0.0	0	0.2	245
	Clothing	2.3	26	5.3	44
	Non clothing textiles	3.0	53	1.8	84
Metals	Ferrous packaging	1.2	58	1.2	66
	Non-ferrous packaging	1.0	104	0.3	112
	Miscellaneous ferrous	0.0	245	1.3	167
	Miscellaneous non ferrous	0.2	172	0.2	218
Hazardous waste	Batteries/Accumulators	0.0	0	0.1	245
	Miscellaneous hazardous waste	0.5	137	1.1	119
Composites	Composite/complex packaging	5.1	53	4.1	39
	Composite/Complex non packag.	2.0	142	5.2	93
	Mixed WEEE	1.1	159	0.8	193
Inerts	Soil and stones	0.0	0	4.0	200
	Miscellaneous inert	7.4	75	10.4	54
Other	Nappies	15.3	57	5.7	33
	Health care/hygiene wastes	0.1	245	0.2	245
	Miscellaneous categories	0.1	210	0.5	245
	Total/Average CV	100	82	100	86

WEEE- waste electric and electronic equipment

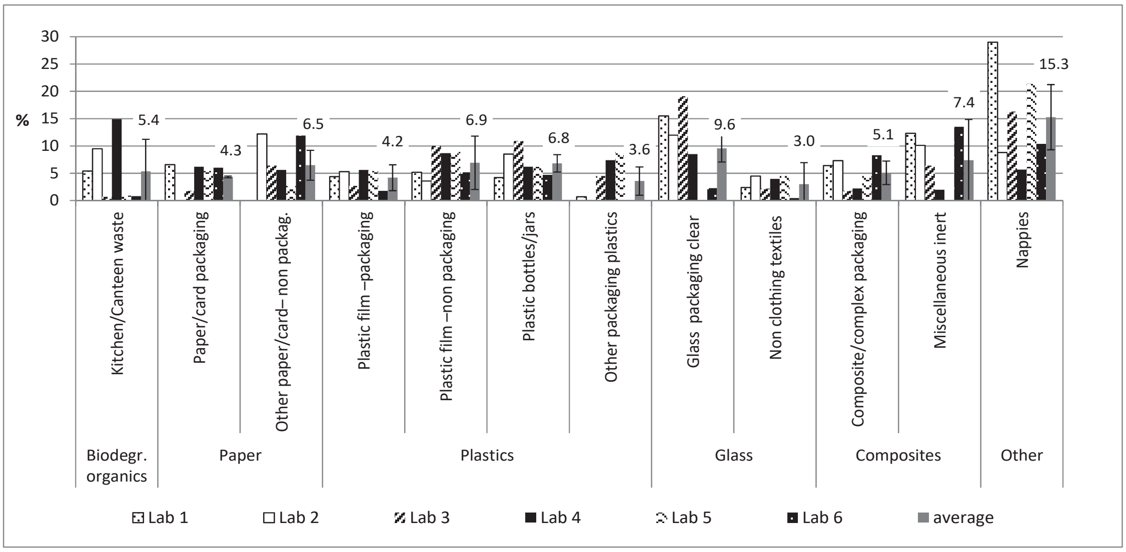

Fig. 7. Detailed material composition of the fraction 80-100 mm (only materials constituting ≥4%) [mass %]

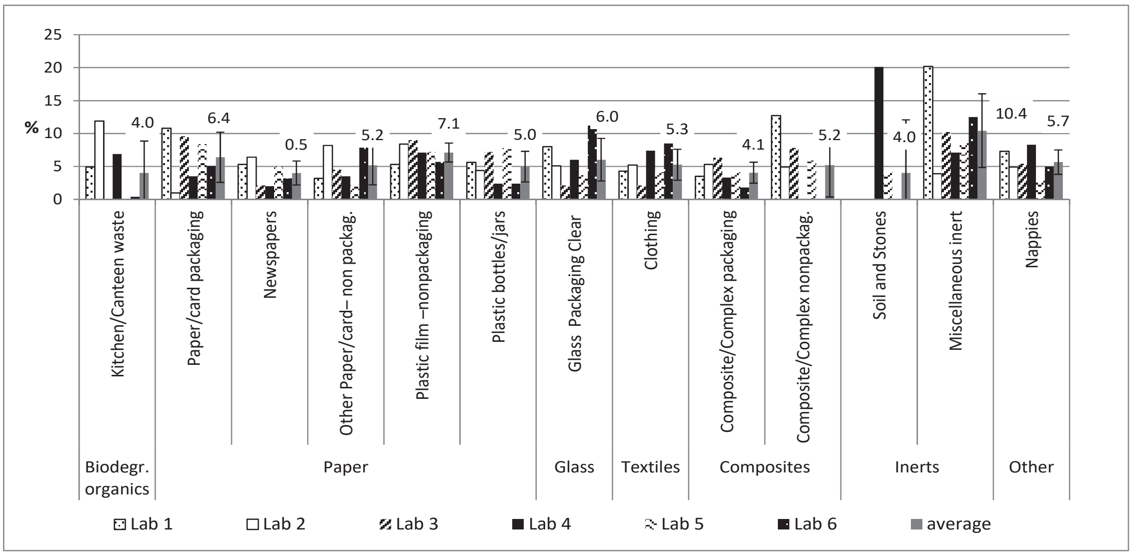

Fig. 8. Detailed material composition of the fraction >100 mm (only materials constituting ≥4%) [mass%]

3.3. Material analysis: comparison between samples

Sample B1 was separated to 13 components, sample B2 to 12 components (excluding fraction 10-20 mm). In case of sample B1, the average CV for all fractions amounted to 44%. For sample B2, the average CV for all materials was 72%. For sample B1, the categories with a content coefficient of variation exceeding 50% were metals, hazardous waste and wood.

These are materials with a relatively low content in waste.For sample B2 content coefficient of variation exceeding 50% was determined in 8 out of 12 categories (metals, composite waste, fines <10 mm, inert waste, other categories, textiles, wood and glass).

3.4. Necessary number of samples

Necessary numbers of samples for a full scale analyses were calculated using CV values obtained in the analyses, individually for samples B1 and B2. The results are provided in Table 3. It can be seen that for the sample size of 100 kg and the more common materials, such as paper and cardboard, plastics, glass, other categories, fines <10 mm, 10-20 mm and inerts basically 10 samples could be enough to provide result at 95% confidence level with max. sampling error of 20%. Assuming the same accuracy, between 10 and 15 samples are needed for organics, textiles and composites. A significantly higher number of samples would be necessary to determine the content of metals, hazardous waste and wood with the given accuracy.

As both metals and hazardous waste should be collected separately, only miss-placed items of these materials can be found in the residual waste. Moreover, metals having high market value, are often separated from residual waste by the waste pickers before the formal collection. Wood is a relatively rare material in household waste. Hence, the high variability of its content.

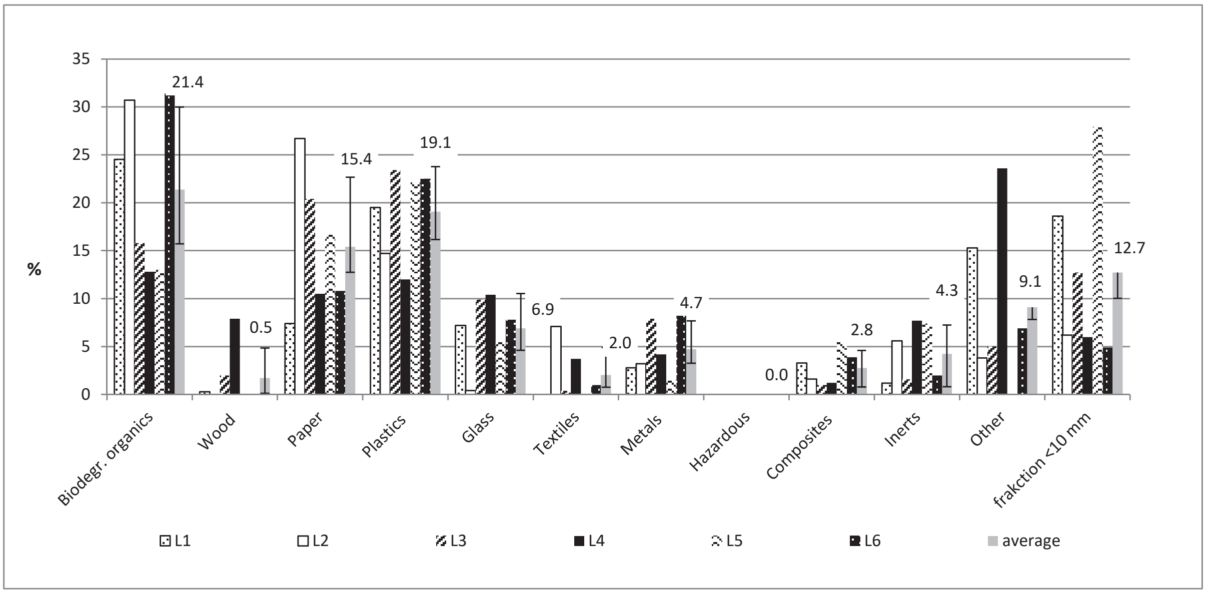

Fig. 9. Material composition of sample B2 [mass %]

For 5 kg samples, up to 50 samples would be needed for most of material fractions, except for other categories, wood and textiles and hazardous waste for which a significantly higher number of repetitions would be needed. 10 samples of 100 kg is a higher sorting effort than 50 samples of 5 kg, however, in the latter case the sampling itself is much more complex. It should be also kept in mind that in the routinely performed sorting campaigns, due to limited time and resources, typically a lower number of samples are sorted, than required. In reality sorting is often reduced fewer or even only one sample. From this perspective it is also better, if the norm prescribes a larger sorting sample size. The number of necessary samples could be minimised after improving the precision of individual measurements**.**

Table 4 shows the necessary number of samples, to determine the material composition of various size fractions. In this case, obviously the necessary numbers of samples are higher.

The total content of plastics and paper and cardboard shows relatively high repeatability, as compared to other main material fractions. However, obtaining reliable results for the detailed material composition (34 fractions) of fractions 80-100 mm and >80 mm needs a significantly (manifold higher) numbers of samples, with exception of the content of some plastics, e.g. plastic films.

4. Conclusions

In this paper the results of inter-laboratory comparison of residual waste composition analyses are presented. The purpose of these tests was to verify the reproducibility of results obtained by six teams applying the proposed sampling and sorting procedure, which is supposed to become part of the new Polish waste analysis standard. The assessment of the reproducibility is qualitative only and was aimed at identifying sources of error which could be avoided by a better formulation of the new standard.

Quantitative assessment of the measurement precision, consisting of repeatability and reproducibility assessment requires a number of repetitions and will be performed at a later stage by the norming body. Comparing the old and the proposed new sorting methodology lead to significant differences in achieved results.

Table 3. Number of samples required to provide statistically valid results

Mass of samples	***B1 100 kg***			***B2 5 kg***		
	CV [%]	***Required number of samples, α = 95%***		***CV [%]***	***Required number of samples, α = 95%***	
Max. random sampling error		e'= 10%	e'= 20%		e'= 10%	e'= 20%
Biodegradable organics	36	51	13	40	63	16
Wood	117	526	132	189	1307	327
Paper and cardboard	17	11	3	47	85	21
Plastics	23	21	5	25	23	6
Glass	22	18	4	53	107	27
Textiles	34	44	11	140	752	188
Metals	73	206	52	62	149	37
Hazardous waste	90	309	77	nd	nd	nd
Composites	39	59	15	66	166	41
Inerts	30	34	9	71	192	48
Other categories	26	27	7	96	354	88
Fraction 10-20 mm	33	41	10	-	-	-
Fine fraction <10 mm	28	30	8	71	197	49

nd – not detected

Table 4. Number of samples required (confidence level α = 95%, max. sampling error e'=20%)

Grain size fraction:		***20-40 mm***	***40-80 mm***	***80-100 mm***		***>100 mm***	
Bio-degradable organics	Kitchen/canteen waste	2	35	60	114	106	139
	Garden/park waste				80		155
	Other biodegr. waste				286		230
Wood	Wood packaging	225	80	149	nd	119	294
	Untreated wood				576		253
	Treated wood				295		344
Paper and cardboard	Paper/card packaging	5	2	12	39	6	34
	Newspapers				68		20
	Non-biodegradable paper				82		86
	Other paper/card non packaging				55		31
Plastics	Plastic film –packaging	8	14	9	14	7	3
	Plastic film – non packaging				13		4
	Plastic bottles/jars				13		21
	Other packaging plastics				116		73
	Non packaging plastics				124		32
Glass	Glass packaging clear	14	43	8	58	44	28
	Glass packaging brown				313		100
	Glass packaging - other				186		113
	Miscellaneous non packaging glass				576		nd
Textiles	Textile packaging	286	21	14	nd	15	576
	Clothing				7		19
	Non clothing textiles				27		68
Metals	Ferrous packaging	63	29	13	32	105	42
	Non-ferrous packaging				103		122
	Miscellaneous ferrous				576		265
	Miscellaneous non-ferrous				269		452
Hazardous waste	Batteries/accumulators	176	123	175	nd	108	576
	Miscellaneous hazardous waste				175		135
Composites	Composite/complex packaging	98	34	12	27	23	15
	Composite/complex non packaging				196		83
	Mixed WEEE				242		355
Inerts	Soil and stones	13	5	32	nd	31	382
Other categories	Miscellaneous inert	182	85	29	54	9	28
	Nappies				32		10
	Health care/hygiene wastes				576		576
	Miscellaneous categories				425		576

nd – not detected; WEEE- waste electric and electronic equipment

Obviously, the precision of the measurement is improved for the larger sample. In case of 100 kg sample, the average CV for all material fractions amounted to 44%, while for 5 kg sample it was 72%. These preliminary results allowed to estimate the required number of samples needed to obtain the final result at a confidence level of 95% and max. sampling error e' of 20%. In case of 100 kg sample 10 repetitions would provide statistically valid contents of the major fractions, even if sorting is done be the different teams). For the sample of 5 kg, up to 50 repetitions would be needed for the same group of materials.

Sorting to 36 material sub-fractions provided very high variability of results between the labs. For materials with a share of less than 4% (in 100 kg samples) many more than 10 repetitions are needed to come to reliable results. This must be taken into consideration when making strategic decisions, e.g. on designing a treatment plant based on the results of waste sorting analyses with a single/few samples only.

The study identified a number of sources of bias in the sorting procedure, which should be eliminated. It is expected that the precision of the results can be enhanced by standardisation of the sorting equipment (shape of the slots and sieving technique). The description of some material fractions, especially biodegradable organics, composites, hazardous waste and other materials must be better defined by the procedure. The depth of sorting, e.g. whether or not to empty and separate packed food from its packaging must be well explained.

Moreover, it should be kept in mind, that the data concerning the content of some fractions is influenced by the waste handling, prior to sorting. In case of this waste composition comparison the waste samples underwent transportation in compaction vehicles prior to sorting, which clearly resulted in the lower detection of biodegradable organics in the sorting samples, as compared to waste samples collected directly from containers.

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