Waste Analysis and Determination of the Average Composition of Municipal Waste With a Focus on the Circular Economy

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Waste treatment represents a significant challenge for society and the environment, and its effective management is essential to achieve a sustainable future. This paper focuses on the sorting, analysis and composition of waste in the context of the circular economy, emphasising the established legislative aspects and separation goals in the European Union. The European Union recognises the urgent need to change the linear model of production and consumption to a circular economy in which waste production is minimised, resources are used sparingly, and product lifetime is prolonged with the environmental impact being minimised. To achieve these objectives, the EU has adopted ambitious legislation to improve waste management systems. In our paper, we will focus on key legislative aspects. We analysed how this legislation sets new targets and requirements for waste separation, introduces extended producer responsibility schemes and promotes recycling and resource recovery. As a result, we will present the implementation of the determination of the average waste composition from the perspective of the Czech Republic and selected sub-regions. This paper will contribute to the discussion on practical aspects of the circular economy and will strengthen the awareness of the necessity of efficient waste management for a sustainable future.

Keywords:
sampling,
stratification,
legislation,
certified methodology,
separation targets,
secondary raw material,
sorting,
waste potential,
material recovery,
recycling

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1 Introduction

Waste is a key issue in the context of global environmental challenges, be it climate change, biodiversity protection or sustainable development. Effective solutions to this issue require a comprehensive approach that includes proper waste disposal, active and especially effective recycling, systematic reduction of waste generation and promotion of innovative product and packaging design. These steps lead to the effective implementation of the circular economy approach.

The circular economy is an economic model that aims to maximise the use of resources and minimise the generation of waste by designing, manufacturing, using and recycling products, materials and resources so that they remain in circulation for as long as possible. This approach stands in contrast to the traditional linear economy where the standard model is to produce, consume and ultimately dispose of waste.

The circular economy follows the so-called "closed cycle." Products should be designed to be durable, repairable and, above all, easily recyclable. At the end of their useful life, the materials from these products are reintegrated back into the production process, which minimises the need for new raw materials and reduces environmental impacts. Circular economy promotes ideas such as product sharing, repair and reuse, to extend the life of products. This model is a key tool in the fight against over-consumption, environmental degradation and waste accumulation. In practice, it means transforming economic systems from linear waste to sustainable and efficient use of resources.

The above parameters are precisely a key aspect of why it makes sense to address waste composition and monitor potential usability of waste as a raw material.

2 Legislative approach

Legislation is a very important part because, in the case of waste, legislation establishes targets and requirements that must be respected. For this paper, the following documents will be analysed:

- Directive (EU) 2018/851 of the European Parliament and of the Council.

- Act No. 541/2020 (Czech law).

Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste. This directive is fundamental in terms of the management of waste management. The Directive sets targets for the material recovery of municipal waste, which are defined as follows:

- A common EU target to recycle 65% of municipal waste by 2035 (55% by 2025, 60% by 2030 and 65% by 2035).

The Directive, for example, gives in Annex IV A as an example of an economic instrument to implement the waste hierarchy the introduction of a volume-based payment system, whereby generators pay for waste based on the actual amount of waste generated and which encourages the sorting of recyclables at source and the reduction of mixed waste.

Furthermore, the following key elements emerge from Directives (EU) 2018/849, (EU) 2018/850, (EU) 2018/851 and (EU) 2018/852) adopted in May 2018 following inter-institutional negotiations between Parliament and Council:

- Common EU target to recycle 70% of packaging waste by 2030.
- Binding target to reduce landfilling to a maximum of 10% of municipal waste by 2035.
- Ban on landfilling of separated waste, requiring separate collection of bio-waste by 2023 and of textiles and household hazardous waste by 2025.
- Promoting economic instruments to discourage landfilling.
- Simplified and improved definitions and harmonised methods for calculating recycling rates across the EU.
- Specific measures to promote reuse and stimulate industrial symbiosis - a by-product of one sector is used as a raw material for another.
- Mandatory extended producer responsibility schemes for producers to market greener products and promote recovery and recycling schemes (e.g. for packaging, batteries, electrical and electronic equipment).
- Reducing the amount of biodegradable waste going to landfill to 75% of the total weight in 1995 by 2010, 50% by 2013 and 35% by 2020.

Act No. 541/2020 Coll. Waste Act

The EU requirements and objectives are subsequently implemented in the Czech legislation within the framework of the Waste Act 541/2020 Coll. From 1 January 2030, it is prohibited to landfill waste with a dry calorific value higher than 6.5 MJ/kg. These wastes, which can be classified as energy recoverable, also include MSW. The calorific value of MSW can be around 9 MJ/kg in the raw state (up to 15 MJ/kg on dry basis), which is well above the above limit. At the same time, as of the same date, waste that can be effectively recycled in the current state of scientific and technical progress cannot be landfilled.

The national requirements and targets for the management of MSW defined in Act No 541/2020 Coll. on Waste also include the following requirements and targets applicable to MSW:

- To increase the level of preparation for re-use and the level of recycling of municipal waste to at least 55% of the total weight of municipal waste generated in the Czech Republic by 2025.
- To increase the level of preparation for re-use and the level of recycling of municipal waste to at least 60% of the total weight of municipal waste produced in the Czech Republic by 2030.
- By 2035, increase the level of preparation for re-use and the level of recycling of municipal waste to at least 65 % of the total weight of municipal waste produced in the Czech Republic.
- To dispose of no more than 10 % of the total weight of municipal waste generated in the Czech Republic by landfilling in 2035 and subsequent years.
- Energy recovery in 2035 and in the years thereafter shall not exceed 25 % of the total weight of municipal waste produced in the Czech Republic.

3 Certified methodology

This part is devoted to the analysis of the potential for material recovery from mixed municipal waste. The potential will be evaluated based on the analyses and fieldwork carried out, which led to the determination of the average composition. The overall approach has been described in great detail within a certified methodology for the

analysis and composition of municipal waste. This methodology was developed within the framework of the TIRMSZP719 project (Kropač 2020), where the Ministry of the Environment of the Czech Republic (MoE) was the main supervisor, and the fieldwork should be carried out according to this proposed guideline. A relatively large number of entities in the Czech Republic are engaged in fieldwork, among the most important are EKO-KOM a.s., Institute of Circular Economy z.ú. and others.

These subjects historically carried out fieldwork without the use of certified methodology (it was not available) and used the procedures used in the research project SP/2f1/132/08 "Research on the properties of municipal waste and optimization of its use". These procedures were always adapted to the needs of the subjects and the objectives set. This resulted in different structures from different subjects, i.e. comparability and especially repeatability of results was eliminated in case more than one subject was sampled.

Comparability and repeatability of results was the main requirement for the design of the certified methodology.

The certified methodology further defines the following parameters:

- Sampling (multi-level stratification, Šomplak 2022).
- Minimisation of economic costs.
- Recommendations for the sampling and transport method.
- Method of sorting, necessary documentation and overall administration.
- The tool for evaluating the data obtained and establishing clear results with the accuracy considered.
- Recommendations for laboratory analysis.

An integral part of the method is the so-called sorting module, which is divided into three main categories of sorting. The MoE sets the requirement that the first two levels are mandatory, and the third is recommended. The sorting module, e.g. at the third level, can be modified according to the needs of the sampling objectives. Specifically, this may be a more detailed specification of e.g. plastics or papers in terms of fractional level, i.e. what is actually in the plastics in terms of e.g. PET

bottles, hollow packaging, films, etc. This approach may be of particular interest from the point of view of different processing facilities, where the potential that may be present in e.g. separate collection can be estimated. An example of a sorting module for all three levels is shown in Figure 1.

I. level	*II. level*	*III. level*	*Weight (g)*
Paper	Packaging	**Cardboard**	
		Other - packaging paper	
	Non Packaging	**Magazines and leaflets**	
		Newspaper and office paper	
	Other		
Plastic	Packaging	**Plastic foils**	
		3D plastic	
		Transparent PET	
		Coloured PET	
		PS	
		Other packaging plastic	
	Non Packaging		
Bio	Kitchen waste	**Fruit and vegetable**	
		Residues from the preparation of fruit and vegetable	
		other food	
	Garden Bio		
Wood			
Glass	Packaging		
	Non Packaging		
Metal	Packaging	**Ferromagnetic**	
		Aluminium	
		Other packaging metals	
	Non Packaging	**Ferromagnetic**	
		Other non packaging metals	
Textil	Clothes		
	other textile materials		
Composite and TetraPak	Tetra Pak		
	Others		
Electrical equipment			
Batteries and accumulators			
Other waste	Diapers and sanitary waste		
	Minerals waste		
	Hazardous waste		
	Complex products		
	Others - without category		
Fine fraction (below 40 mm)			
Fine fraction (below 20 mm)		**Ash**	
		Other organic waste	
Fine fraction (below 10 mm)		**Ash**	
		Other organic waste	

Figure 1: Sorting module

Source: own.

3.1. Practical application of the methodology

The results presented in this paper are part of the results of the TIRSMZP719 and CEVOOH projects. The results were obtained by implementing a sampling programme by a certified methodology also developed within the TIRSMZP719 project. The main motivation for developing the methodology was mainly the comparability and repeatability of the results.

The analyses aimed to establish the average composition of mixed municipal waste in the Czech Republic in the detail given by the certified methodology and to obtain a national tool comparable to similar tools for monitoring the composition of

MMW[1] in other EU countries. Given the limited resources for carrying out the analyses (fieldwork), a multi-stage stratification was adopted. The stratification is voluntary within the certified methodology. First, all municipalities in the Czech Republic (6 258 municipalities in total) were considered and then divided into individual similarity groups (clusters or clusters). Small municipalities, and military areas were excluded from the clustering (2 443 municipalities). Ten clusters were created with the following characterization:

- C1 Cities - local "district" centres.
- C2 Regional towns and regional centres.
- C3 Towns with rural character.
- C4 District towns - tens of thousands of inhabitants.
- C5 District towns - up to ten thousand inhabitants.
- C6 Rural municipalities A.
- C7 Rural municipalities B.
- C8 Rural municipalities C.
- C9 Rural municipalities D.
- C10 Capital city of Prague.

From the above distribution, 10 representatives and 10 alternates were selected to represent the characteristics (freely available information from the CSO[2]) of each cluster. The selected representatives were contacted and cooperation on sampling possibilities was agreed. Each representative was provided with the necessary technical equipment (pedestals, 40-20-10 sieves, samplers, etc.) and space was secured to carry out the fieldwork. Towards the end of the project, sampling also took place in other locations (beyond the 10 selected representatives).

Sampling was based on the technical capabilities of each site, always involving the collection of specific containers or the provision of specific collections. For these purposes, the BinGen tool was used to randomly select containers in a given village. Of course, the key was to have a complete list of bins so that random selection could

[1] Mixed municiapl waste
[2] Czech Statistical Office - www.czso.cz/csu/czso/home

take place. In localities where this information was unavailable, a street draw was made from which samples (containers) were randomly taken.

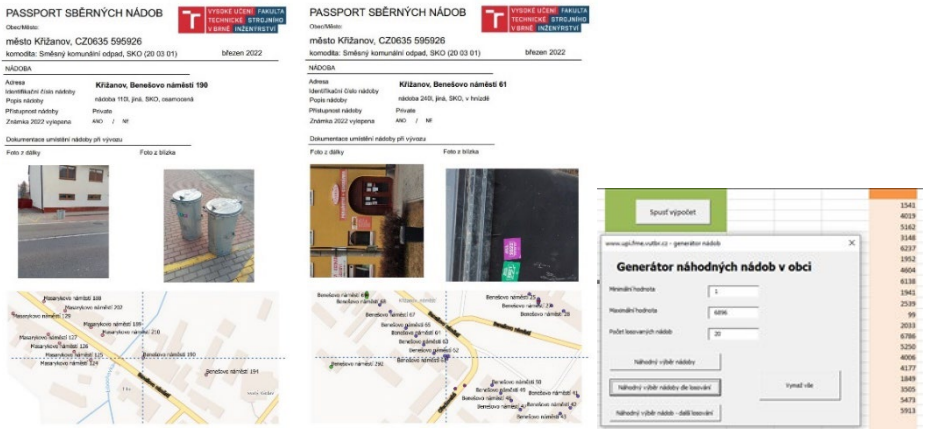

Figure 2: BinGen and export of selected bins

Source: own.

3.2 Waste composition for the Czech Republic

It is not recommended to carry out the analyses according to the proposed methodology from compactor collection vehicles. If a mixed sample is to be generated and a collection vehicle is used, it is strongly recommended not to separate the waste. Compaction, significantly affects the results, i.e. moisture transfer, contamination, ability to sort the individual components being monitored properly, etc.

Based on the certified methodology, a sample of 1 100 l has been determined as a representative sample. At the same time, a sample from the so-called bag sample may be used, again in an appropriate proportion to the representative sample.

The total number of investigated (sub) samples was 635 with a total tonnage of 19.6 t. In the framework of the fieldwork, the sorting was carried out to level III (the mandatory level according to the certified methodology is level I and II; level III is recommended):

- Level I (first) sorting - 635 sub-samples, approx. 19.6 t.
- Level II (second) sorting level - 631 sub-samples, approx. 19 t.
- III (third) sorting level - 609 sub-samples, approx. 15 t.

The sampling was carried out in Brno, Louka, Valašské Klobouky, Třebíč, Křečkov, Velké Popovice, Červené Řečice, Křižanov, Kralupy nad Vltavou, Hradec Králové, Polná and Prague. The length of fieldwork was about a year and covered all seasons (taking into account seasonality), in the period 3/2020-8/2021 - fieldwork was interrupted due to the COVID-19 pandemic.

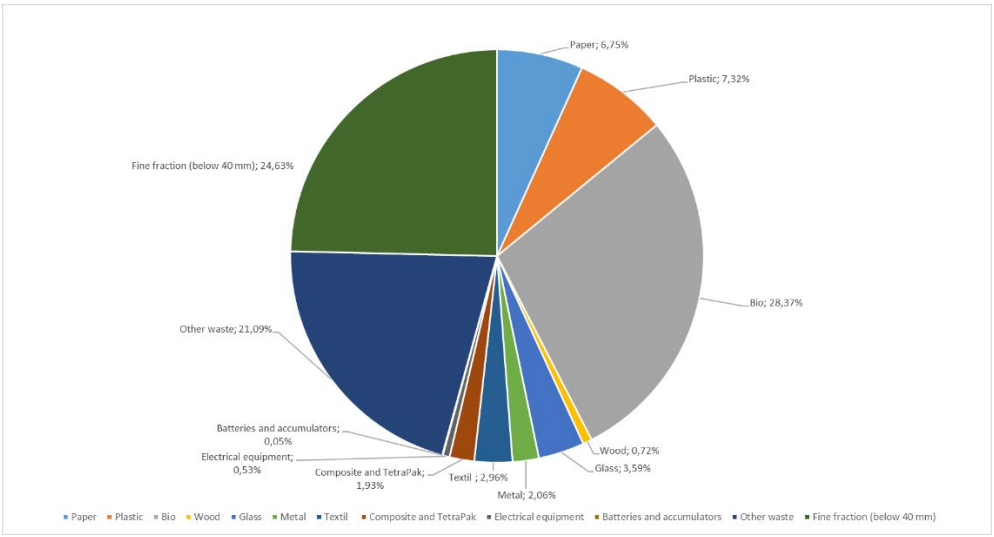

Figure 3: Average composition of municipal waste
Source: own.

4 Analysis of material recovery potential

The average composition shows that the largest parts belong to the following fractions:

- Bio waste - approximately 29%.
- Other waste - approximately 21% (significant dominance of sanitary waste)
- Fine fractions (aggregated) - approximately 25%.

- Paper - approximately 7%.
- Plastic - approximately 7%.
- Other commodities (categories) below 5%

Where specific components that are potentially material recoverable are concerned, these are prioritised (synergies with separate collection):

- Plastic
- Paper
- Glass
- Metal
- Textile
- Bio
- Batteries
- Electrical equipment
- Wood

From the above categories, a theoretical estimation of the potential from MMW that can be redirected to separate collection or to other locations relevant to separate waste collection will be made.

4.1 Plastic waste

Plastic waste is as standard collected separately in the form of a yellow bin. What goes in the bin can vary in place and time, so it is necessary to see at each location what can be put in the bin. The following items can be diverted in whole or in part from the MMW:

- Films - approx. 3.5% - the assumption for diversion is 1 - 1.5% (these are films or bags in which waste is disposed of, it is assumed that waste bags and sacks will always be present in the MSW as this is the primary packaging for waste, therefore a conservative approach is set that approximately one-third of films can be diverted)

- 3D plastics - approx. 2% - the assumption for diversion is a total of - 2% (3D packaging plastics, these are preferably hollow packaging or primarily HDPE packaging, which can be easily diverted to the yellow bin)
- PET clear and coloured - approx. 1% - the assumption for diversion is an overall amount of - 1% (PET beverage bottles can be completely diverted to the yellow bin or the backup stream)
- PS – 0.1 % - the assumption for diversion is a total amount of approx. 0.1 % (polystyrene packaging can be completely diverted)
- Other Packaging - 0.1% (no assumption of direct diversion for other packaging components, so the total is retained)
- Other non-packaging - 0.4% - assumption for redirection is approximately half - approximately 0.2% (here the assumption is that approximately one half of the component can be redirected to the yellow bin, although it will not be consistent with the packaging component share and EKO-KOM's rewards)

The total diversion potential for plastics is about 3.5%.

Figure 4: Example of plastic waste after sorting
Source: own.

4.2 Paper waste

Paper waste is as standard collected separately in the form of a blue bin. The blue bin is locally very similar in terms of packaging materials. An exception is municipalities that also collect e.g. tetra-pack in the blue bin. The following components can be fully or partially diverted from the MMW:

- cardboard and cardboard (packaging part) - 2.5% - the assumption for diversion is a total amount of - 2.5%.
- magazines and leaflets - 1% - the assumption for diversion is a total of 1%.
- Newspaper and office paper - 1% - the assumption for redirection is a total amount of - 1%.

The total potential for redirection for paper is approximately 4.5%.

Figure 5: Example of paper waste after sorting
Source: own.

4.3 Glass waste

Glass waste is as standard collected separately in green (coloured) or white (transparent) containers. The glass containers can be, for example, connected with two inlets and an internal partition or they can be two separate containers. The following components can be fully or partially diverted from the MMW:

- Glass - packaging - 3.3% - the assumption for diversion is a total amount of - 3.3%.
- Glass - non-packaging – 0.2 % - the assumption for diversion is a total amount of 0.2 %.

The total potential for diversion for glass is about 3.5 %.

Figure 6: Example of glass waste after sorting
Source: own.

4.4 Metal waste

Metal waste is as standard collected in a grey bin. The following components can be fully or partially diverted from the MMW:

- Ferromagnetic - 1% - the prerequisite for diversion is the total amount of - 1%.
- Aluminium - 1% - the assumption for diversion is a total amount of - 1%

The total potential for redirection for metals is approximately 2%.

Figure 7: Example of metal waste after sorting
Source: own.

4.5 Textiles waste

Textile impacts are collected in separate containers or textiles can be taken to collection centres or directly to the Salvation Army. There can be a small complication with textiles in that some may fall outside the waste inventory. Given

that it is a relatively heavy (by weight) component, it can be concluded that this particular stream may have an impact on meeting recycling targets. At the same time, it should be noted that from 1 January 2025 there is an obligation to ensure a separate collection of textiles in all municipalities. In this respect, textiles can be considered to be diverted entirely out of the MMW, approximately 3%.

Figure 8: Example of textile waste after sorting
Source: own.

4.6 Biowaste

Collection of bio-waste is highly variable. Some municipalities use bio-waste collection in the form of home composting (waste enters the off-register waste management system), or separate collection in the form of brown bins or a centralised collection point for bio-waste or ad-hoc collections in case of seasonality. Of course, there are also municipalities where no collection of bio-waste is yet in place. Alternatively, it may be a combination of the above. The results of the fieldwork carried out show that bio-waste represents almost a third of the total black bin. A significant added value in diverting bio-waste from the black bin to the brown bin is the introduction of a door to door system, which was also confirmed in the fieldwork. It is indeed the introduction of a door to door system, the situation will not be improved by providing e.g. home composters.

- Fruit and vegetables - approx. 5% - these are whole pieces of fruit and vegetables that can easily be diverted to material recovery, from a conservative perspective it will be chosen that 80% will go outside the MMW, i.e. 4%.

- Vegetable residues from fruit and vegetable preparation - approx. 8% - this is one of the residues from the preparation of fruit and vegetables, this part is suitable for composting or use within the biogas station. It is assumed that half of this component can be redirected, i.e. 4%.
- other food products - approx. 11% - this is the component mainly related to food residues, which are preferably of animal origin. In this respect, a pessimistic scenario will be set and no redirection will take place.
- from gardens and parks - about 6% - this is material that comes from gardens and parks, i.e. primarily green maintenance. Here the assumption is that the total stream can be diverted away from the MSW and in the form of composting. Thus, the total flow will be redirected in the full 6%.

The total potential for diversion for BIO waste is about 14%.

Figure 9: Example of Bio waste after sorting
Source: own.

4.7 Batteries

Batteries are not collected separately in the Czech Republic in the form of container collections. They are end-of-life products and can be disposed of in collection centres or other designated places, e.g. shops and shopping centres (e.g. together with fluorescent lamps). The whole category can be completely diverted from the MMW, which reaches a value of about 0.1% in terms of average composition.

4.8 Electrical equipment

Similar to the battery category, electrical equipment is not collected separately in the Czech Republic in the form of containerised collections. They are end-of-life products and can be disposed of in collection yards or other designated places. The

entire category can be completely diverted from the MMW, which is about 0.5% in terms of average composition.

Figure 10: Example of electrical waste after sorting
Source: own.

4.9 Wood (furniture and similar material)

Wood, or it may be bulky waste, is collected in the Czech Republic under the collection yard regime. These collection yards operate on the principle of either re-use centres or energy recovery. The total stream of wood (treated only) can be diverted out of the MMW stream, in full. This will be approximately 0.7%.

5 Conclusion

This paper summarises an approach to waste composition analysis, where a large number of samplings were carried out throughout the Czech Republic (2020 - 2022). A detailed analysis of the separation targets set and other important steps that are key in waste management was analysed in the framework of legislation. It was necessary to analyse the potentially recoverable materials contained in the mixed municipal waste container. The research team carried out more than 600 samples with a total weight of 20 t during two years of field research.

Based on practical experience, e.g. from sorting lines (Gregor 2018, CET), an estimate was made to evaluate the potential amount of waste that can realistically be diverted from mixed municipal waste. The potential was assessed rather conservatively, especially focusing on the possibility of introducing a door-to-door system or e.g. collection of dry recyclables (Gregor 2018). From the expert

assessment, it was evaluated that approximately 32% (by weight percentage) of mixed municipal waste (black bin) can be effectively diverted into separated components.

This relatively large potential can effectively contribute to high separation targets and appropriate waste handling/recycling.

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