Agronomy Research **19**(S1), 961–974, 2021
https://doi.org/10.15159/AR.21.081

Comparison of physical composition of municipal solid waste in Czech municipalities and their potential in separation

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Received: February 23rd, 2021; Accepted: May 2nd, 2021; Published: May 17th, 2021

Abstract. Czech Republic has been moving from landfill-based waste system toward resource-based waste management system with an increasing rate of recyclable waste in the last years (38.6% of recycling by material and 11.7% of energy recovery in 2018). However, landfill is still a popular way of mixed municipal solid waste (MMSW) disposal due to the low tax. In the Czech Republic, MMSW is collected from households by door-to-door system or recovery operations (Household Waste Recycling Centre) and only should consists of everyday items, which are further non-recyclable and non-reusable. However, a significant amount of recyclable waste can still be found in MMSW. Therefore, a good knowledge of the physical composition of MMSW is required to define strategy plans and improve waste management in municipalities. This work is aimed at comparing the physical composition of MMSW in the Czech Republic with small municipalities up to 2,999 inhabitants and big municipalities from 3,000 inhabitants to recognize the share of recyclable and non-recyclable waste in MSW and designate the potential of separation at source. Composition of MMSW was determined by a physical evaluation of waste collected from households in target municipalities which consists in a detailed manual sorting of waste into 13 specific groups according to their types, and weighting by a scale. We found that the real proportion of MMSW that could no longer be reused or recycled was much less than the amount disposed of in the municipal waste bins. A large part of MMSW consisted of organic waste together with food waste. This type of waste is especially useful when people turn it into compost to prevent the production of waste and it returns the nutrients back to the soil, closing the circle. The rate of recyclable waste was also high in many municipalities covered by our analyses, which indicated a lower rate of separation and reflected an insufficient sorting system in municipality and insufficient education of inhabitants. On the other hand, it points to the larger space of separation potential in households. In conclusion the evaluation emphasizes the improper proportion of MMSW in Czech municipalities. A lot of waste can be recycled but once it is thrown into black bins as MMSW, there is no chance that it will be reused/recycled. It therefore calls for measures to improve sorting at source, which will benefit municipal authorities in term of increasing recycle rates in order to comply with regulations and make a profit. We found the analysis of the physical composition of MMSW as a fundamental method for municipalities to verify the separation rate at the source, and it is recommended to conduct this analysis regularly and monitor developments.

Key words: physical analysis, waste composition, municipal solid waste, separation at source, Czech Republic.

INTRODUCTION

In 2018, the Czech Republic produced 5,782 thousand tons of mixed municipal solid waste (MMSW) which represents 544 kg of MMSW per person, about 52 kg more than the European average (492 kg). In this year Denmark generated the most municipal waste per capita among the EU Member States, on the other hand they are also front runner in diverting waste from landfilling, mainly through incineration with energy recovery (European Commission, 2020a). In the Czech Republic, only 38.6% of municipal waste was recycled by material and 11.7% for energy recovery, 46% was landfilled (Ministry of the Environment, 2019). Thanks to one of the lowest landfill tax in Europe (€20 in CZE, the tax in EU varies from €5 to more than €100) (CEWEP, 2020), landfilling as a way of waste disposal is still popular in Czech municipalities, especially in small municipalities with a low budget.

However, a number of European legislations pushes their members into transition to a circular economy. A new Circular Economy Action Plan presents key elements including a target of recycling 65% of municipal waste by 2030 and reducing landfill to a maximum of 10% of municipal waste in the same year. In addition, there is a strict ban on landfilling separately collected waste, for example paper, plastics, organic waste, metals, etc. (European Commission, 2020b). This is a strong message for the Czech Republic to set up higher strategy targets for waste recycling, recovery and diversion from landfill. The Czech Waste Management Plan 2015–2024 has stipulated that a landfill tax should be adjusted so that waste is redirected higher up the hierarchy (Ministry of the Environment, 2014). The increase in the landfill tax from €20 to €74 per ton to be applied in 2030 should shift more waste treatment to recycling and reuse instead of landfilling. This step would have a significant impact on the municipality's budget and would force small municipalities to focus on waste treatment and try to find a new way of waste disposal produced in their region. Thorough understanding the quantity and composition of a waste production is important in improving quantities of potentially recyclable materials and to forecast future waste generation (Parfitt & Flowerdew, 1997; Parizeau et al., 2006). The composition and variation of waste is also important in the design and implementation of appropriate sorting and recycling technologies (Burnley, 2007).

The composition of the produced waste is extremely variable and depends on multiple seasonal and cultural factors, dietary habits and socio–economic and legal impacts. This variability makes the definition and measurement of waste composition both more difficult and necessary (Kreith, 1999; Dehghani et al., 2009; Diaz et al., 2020). Accurate information on the quantities and characteristics of solid waste can then be used for the design, implementation and operation of the best practice in waste management as well as resource control and saving, recycling, waste collection planning, transport, and disposal system ultimately leading to environmental protection against such harmful effects (Heravi et al., 2013; Erami et al., 2015). Assessing the composition of waste provides a detailed view of the municipal waste produced by citizens every day and inspires authorities to make further improvements. To study the quantity and composition of municipal waste, there is no adopted international standard but various working standards on national level (Dahlen & Lagerkvist, 2008), even though there is an up-to-date document providing methodology for solid waste composition analysis from 2014 called SWA-Tool for European countries, it is not obligatory and does not meet current requirements (Kropáč et al., 2020). Therefore, each member of EU has developed its own methods based on the individual waste background with varying numbers of material fractions and sorting objectives (Edjabou et al., 2015). The method used in this project has its base in national method and inspired most by French MODECOM methodology characterized by at least 2 tons of MMSW, from which 500 kg for sampling (Montejo et al., 2011). In Austria and Germany, there are methodologies at the level of individual Lands and regions (Vogel et al., 2009; Kern & Aiwpwnkorhwn, 2010). From the other continent, American Society for Testing and Materials (ASTM) evolved a number of methods for local governments or industrial plants including Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste, suitable not only for US, but worldwide (Dahlen & Lagerkvist, 2008).

To this end, the non-governmental organization Institut Cirkulární Ekonomiky z. ú. (INCIEN) in cooperation with JRK Czech Republic s.r.o. (JRK) conducted analyses of the physical composition of the MMSW to help municipalities gain better knowledge of their waste. Thanks to their work and the data collected, this paper could emerge.

This study investigates the physical composition of a mixed municipal solid waste material. The primary objective is to evaluate all obtained data of selected municipalities and provide an initial overview on waste composition in the Czech Republic. It includes using various statistical tools focusing on the qualitative and quantitative characteristics of the MMSW and comparing the municipalities for recognising the composition differences. Then, the factors affecting composition of the MMSW are identified and lastly, the potential trends for reducing waste and increasing recycling are determined for guiding prospective steps in planning and environmental assessment of waste management.

MATERIALS AND METHODS

All analyses of physical composition were completed by the Institut Cirkulární Ekonomiky, z.ú in cooperation with JRK Czech Republic, s.r.o., whose main objective is to transform and implement the circular economy in the Czech Republic.

The aim of the field analysis was to evaluate the mixed municipal solid waste and its physical composition of recyclable and non-recyclable compounds, to determine their percentage and to identify the potential for improving recycling rates. The methodology was designed according to the Waste Sampling Methodological Guideline (Ministry of the Environment, 2008) and adjusted to meet the waste analysis objective. The assessment of the physical composition of the MMSW was carried out in a total of 35 Czech municipalities grouped into 2 categories: small municipalities (SM) with a population up to 2,999 citizens and big municipalities (BM) with a population of more than 3,000 citizens. Some analyses were repeated upon request to monitor changes in the composition of municipal waste over a four-year testing period.

Waste samples were collected from households (both urban centres and family houses) randomly distributed among selected municipalities during each field analysis. All analyses were carried out in cooperation with the municipal authorities who provided samples of MMSW collected from households. For analysis, a sample of approx. 500 kg of randomly picked municipal waste was taken and analysed. Protective equipment (suits, gloves, goggles, respirators, etc.) was used throughout the analysis. Each sample of MMSW was waded through carefully and manually divided into 13 detailed categories (Fig. 1). Each separate category was weighed using a digital scale and recorded, followed by calculation of the total weight at the end. All the data was recorded and photographed. Following analysis, all waste samples were disposed in compliance with the policy.

Finally, all separated waste (paper, plastics, glass, etc.) was counted as a percentage (rate), where 100% is the total weight of the waste sample from each municipality (formula below).

$$\frac{weight\ of\ separated\ waste\ category\ \text{(kg)}}{waste\ sample\ in\ total\ \text{(kg)}} * 100 = rate\ (\%)$$

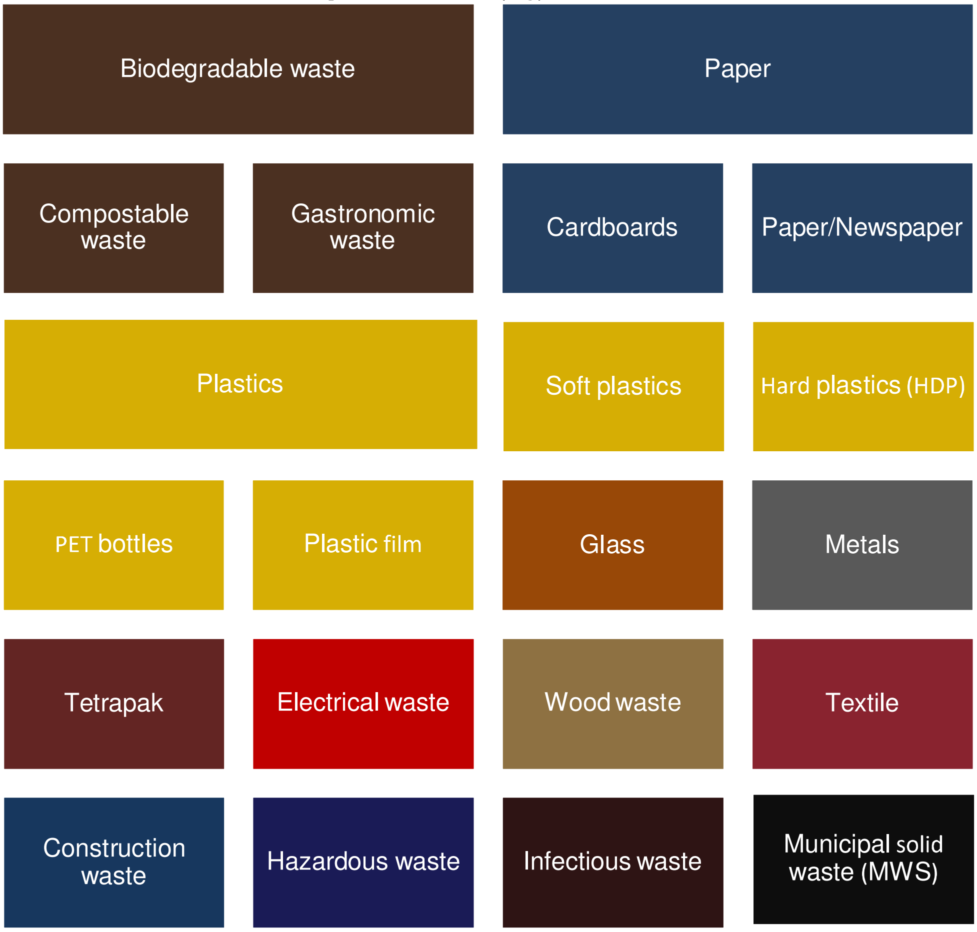

Figure 1. Categories of waste in which waste samples were separated during analysis.

Program R (R Core Team, 2016) was used for statistical analysis of the collected data to compare the difference in MMSW and recycling potential between municipalities. All the data were tested to assume normality of parametric testing using the Shapiro-Wilk test (Shapiro & Wilk, 1965) but none met normality requirements, therefore all data sets were considered non-parametric, and non-parametric statistical methods were used for testing. The Fligner-Killeen test was chosen to check the homogeneity of variance to verify differences in waste composition between municipalities. It is a non-parametric alternative to the F-test with a robust tolerance against normality deviation. The correlation of selected waste types with the population was tested using Kendall's Tau statistic determined for non-parametric data. Data on wood waste were recorded and used to visualize the results, but excluded from statistical analysis due to their insignificant portion (0 in most of samples) in all municipalities as this might distort the statistics.

RESULTS AND DISCUSSION

The objective of assessing the physical composition of mixed municipal solid waste is to define the structure of the MMSW. The structure can tell a lot about the waste management in borough, particularly it can reflect citizen's behaviour in relation to waste recycling and disposal. Thirteen MMSW components were assessed in the waste samples, namely organic waste, plastics, paper, glass, metals, Tetra-Pak, electronic waste, textiles, wood, construction waste, infectious, hazardous and mixed municipal solid waste. These are the main components of household waste. An overview of the physical composition of the MMSW is given in the figures below.

Average values of physical composition of MMSW

(Descriptive statistical summary)

Figs 2 and 3 provide an overview of the data from the analysis of the physical composition and depict the average part of the waste compounds found in the MMSW samples based on their weight. The waste samples produced a non-recyclable fraction representing actual mixed municipal solid waste accompanied by hazardous and infectious waste created only approx. 37% of MMSW in small municipalities (SM) and 33% in big municipalities (BM) (Fig. 2), the remaining part was created by recyclable compounds that should not end up in the bins designated for non-recyclable waste. Most recyclable compounds were generated by organic waste (29.54% for SM and 24.95% for BM) followed by plastics (SM: 11.38%; BM: 11.99%), paper (SM: 5.93%; BM: 10%), textile (SM: 5.78%; BM: 5.1%) and glass (SM: 4.62%; BM: 5.6%).

The largest portion of the MMSW was represented by organic waste (the sum of compostable yard–waste and gastronomic waste), which was also confirmed in other studies in Crete (Gidarakos et al., 2006), China (Ma et al., 2020), Egypt (Abdallah et al., 2020), Iran (Dehghani et al., 2009; Phillips & Gholamalifard, 2016), Western Algeria (Guermoud et al., 2009), Ghana (Miezah et al., 2015), etc. According to the study data comparing waste–related characteristics between the developed and developing countries showed, that the food waste fraction was larger in the lower-income developing countries compared to that in the USA and EU countries (Abu Qdais et al., 1997), which is supported by another study with finding that the low-income areas produce larger organic share than high-income ones (Ogwueleka, 2009). Organic waste (the sum of compostable yard-waste and gastronomic waste) in the MMSW is a quantitatively essential category of waste and the way it is treated can have a positive and negative impact on environmental and economic aspects in municipalities (Chotovinský & Altmann, 2017).

The ratio of plastics in the MMSW is surprisingly low (around 10%) compared to organic waste, but their amount is much larger and takes up much more space in waste bins. That is because our study ratios were calculated based on weight, therefore plastic had a lower share. Plastic waste included a large number of PET bottles which are easy to reuse and recycle. Recently, the thorny issue of the PET deposit system has emerged in the Czech Republic. The main objective of operating the deposit system will be to save bottles from landfilling, which will also guarantee the good quality of bottles returning back to producers. In addition to the PET bottles, plastic films, soft and hard plastics were also found in the waste sample.

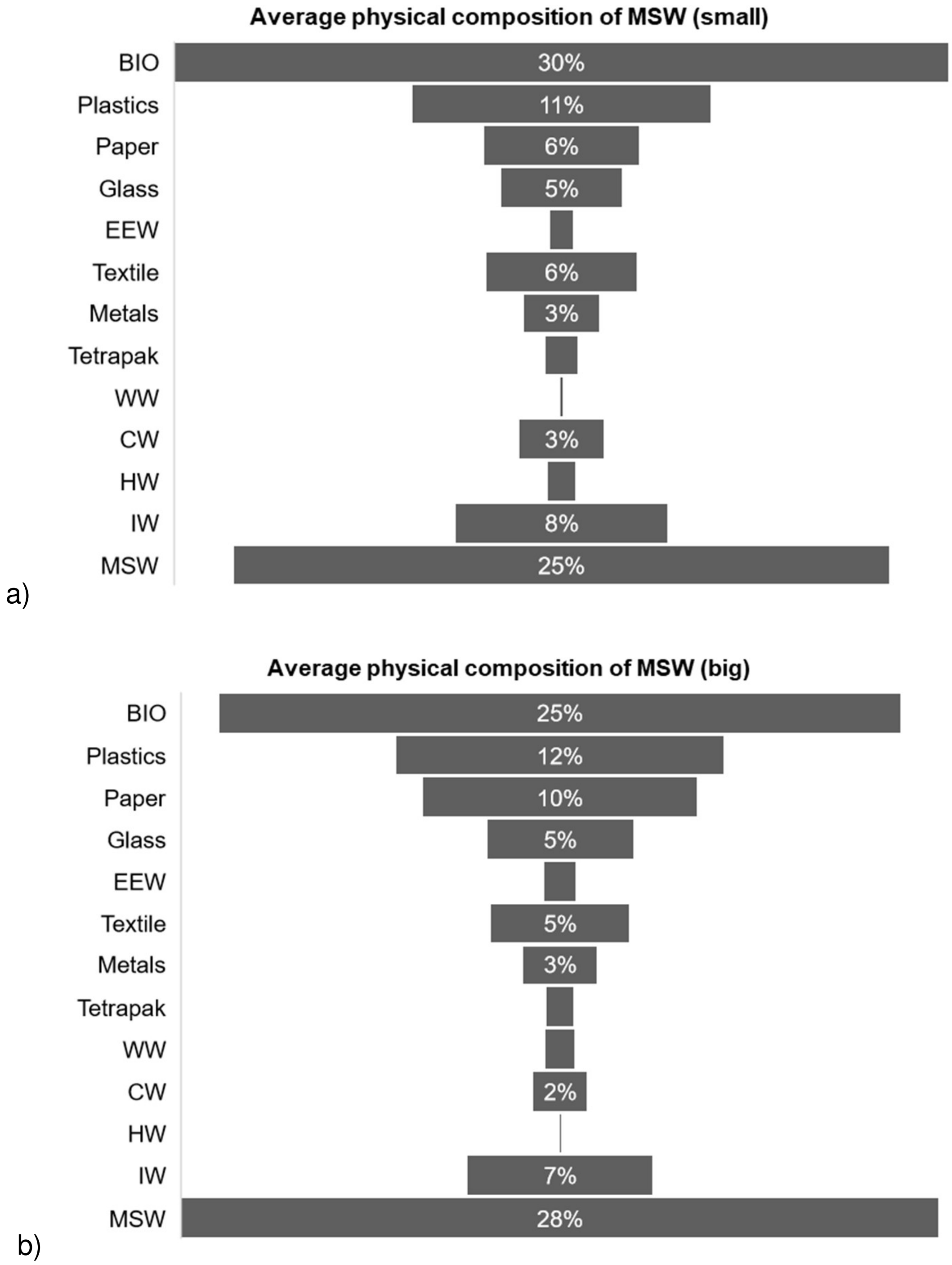

Figure 2. Average physical composition of municipal solid waste in the selected municipalities of this study: a): small municipalities; b) big municipalities. **Abbreviations**: BIO – organic waste; EEW – electrical and electronic waste; WW – wood waste; CW – construction waste; HW – hazardous waste; IW – infectious waste; MMSW – mixed municipal solid waste.

Unlike plastics, paper waste had an unequal proportional rate in small and big municipalities. While in small municipalities paper had only 5,93% share in the MMSW, big municipalities had almost twice the share than SM (10%). But both plastic and paper waste has similar properties in terms of volume. Large uncompressed packages may take up much more volume but their weight in MMSW is much lower. Pressing can help to reduce the volume of paper packaging to 20% of its original volume and achieve substantial savings in logistics costs (Chotovinský & Altmann, 2018).

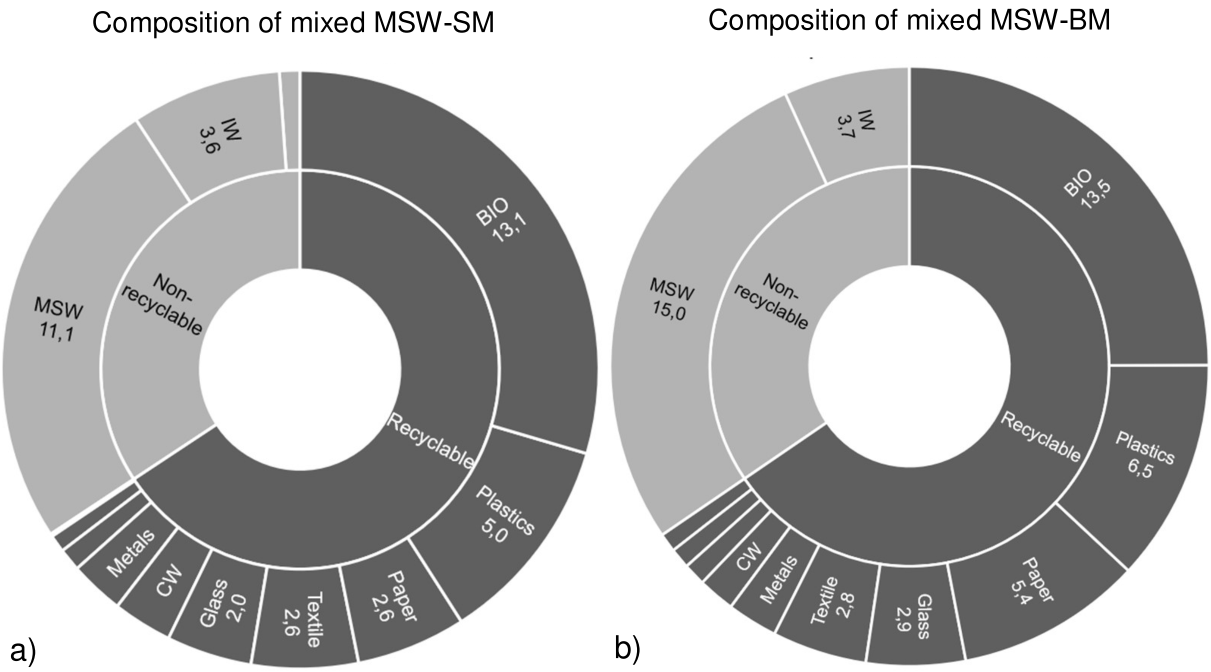

Figure 3. Average fraction of recyclable and non-recyclable waste divided according to their type: a) small municipalities; b) big municipalities. Municipal solid waste is a type of waste that no further use but is destined for incineration (energy recovery) and landfill. According to this figure, more than fifty percent of usable/recyclable waste still existed but ended up in mixed waste bins.

Construction waste was present in less significant quantities in the MMSW, but still accounted for more than 3% of the MMSW. Sometimes electric waste could also be found in MMSW, accounting for approx. 1% of the waste sample, similar to the Tetra Pak (liquid packaging board). Clearly, non-recyclable MMSW produced by households were actually much smaller than those thrown in the municipal waste bins.

As it represents a significant amount in the MMSW, organic waste and plastics were specifically tested between municipalities. Plastic waste had a small range from 3% to 16% of the MMSW, while organic waste was more variable; one municipality had even more than 50% of the MMSW generated by organic waste, another 4 had over 40% and the average rate is 29.5% of the total MMSW for small municipalities and 25.8% for big municipalities. These results showed that plastic and organic waste from kitchens and horticulture is often thrown in the municipal waste bin instead of being recycled. On the other hand, this signals the potential for improving recycling at source.

Test of homogeneity of variances

The variability of the data was tested by a non-parametric alternative to the *F-test: the Fligner–Killeen test of homogeneity of variances*. The aim of this method was to verify the variability of the date on waste structure in the different municipalities. The null hypothesis proposed that the variability in waste structure did not differ between municipalities. The result of this test did not reject the null hypothesis for small (*p-value* = 0.9989) municipalities, meaning that there was no evidence of significant differences in the waste structure of the individual components were found in all small municipalities. The big municipalities have sketched the result of variability, such as small municipalities. The *p-value* of *Fligner–Killeen test* was 0.7922, so the null hypothesis was not rejected and demonstrated a similar structure in the MMSW in big municipalities as well.

Correlation measure

Small municipalities (< 2,900 inhabitants):

The relationship between the population and the composition of the waste was tested to see if the quantity of waste categories can be affected by the size of the population. The data was analysed using a non-parametric method - the *Kendall's correlation tau*. The results revealed no significant correlation, unless in one case a negligible sign of correlation of hazardous waste with the population was demonstrated (*p-value* = 0.08419). It revealed a positive regression (*Kendall's tau* = 0.3109) pointing out that the amount of hazardous waste in small municipalities might be bigger as the population grows (Fig. 5). For all other waste categories, no correlation with population size was demonstrated (*all p-values* > 0.05).

Big municipalities (> 30,00 inhabitants):

like small municipalities, big municipalities revealed a much more correlation between population size and waste quantities, and mostly in a positive direction. The amount of plastic (*p-value* = 0.011) and paper waste (*p-value* = 0.00071) in the MMSW increased as the population grew, as did the MMSW (*p-value* = 0.0165). A negative correlation was shown for infectious waste, where a growing population could have a decreasing effect on the amount of infectious waste (Fig. 5).

Even the results of our study on the correlation between population size and waste structure were not as significant as in another study (Han et al., 2018), population size still appears to be one of the waste-elated characteristics that can influence the structure of the MMSW, alongside city size, economic activities, lifestyle and geographical location (Lebersorger & Schneider, 2011; Ma et al., 2020; Nguyen et al., 2020). The population aspect can be expanded to include detailed issues such as gender and age structure, education or unemployment rates, which all have an impact on waste production and composition (Talalaj & Walery, 2015).

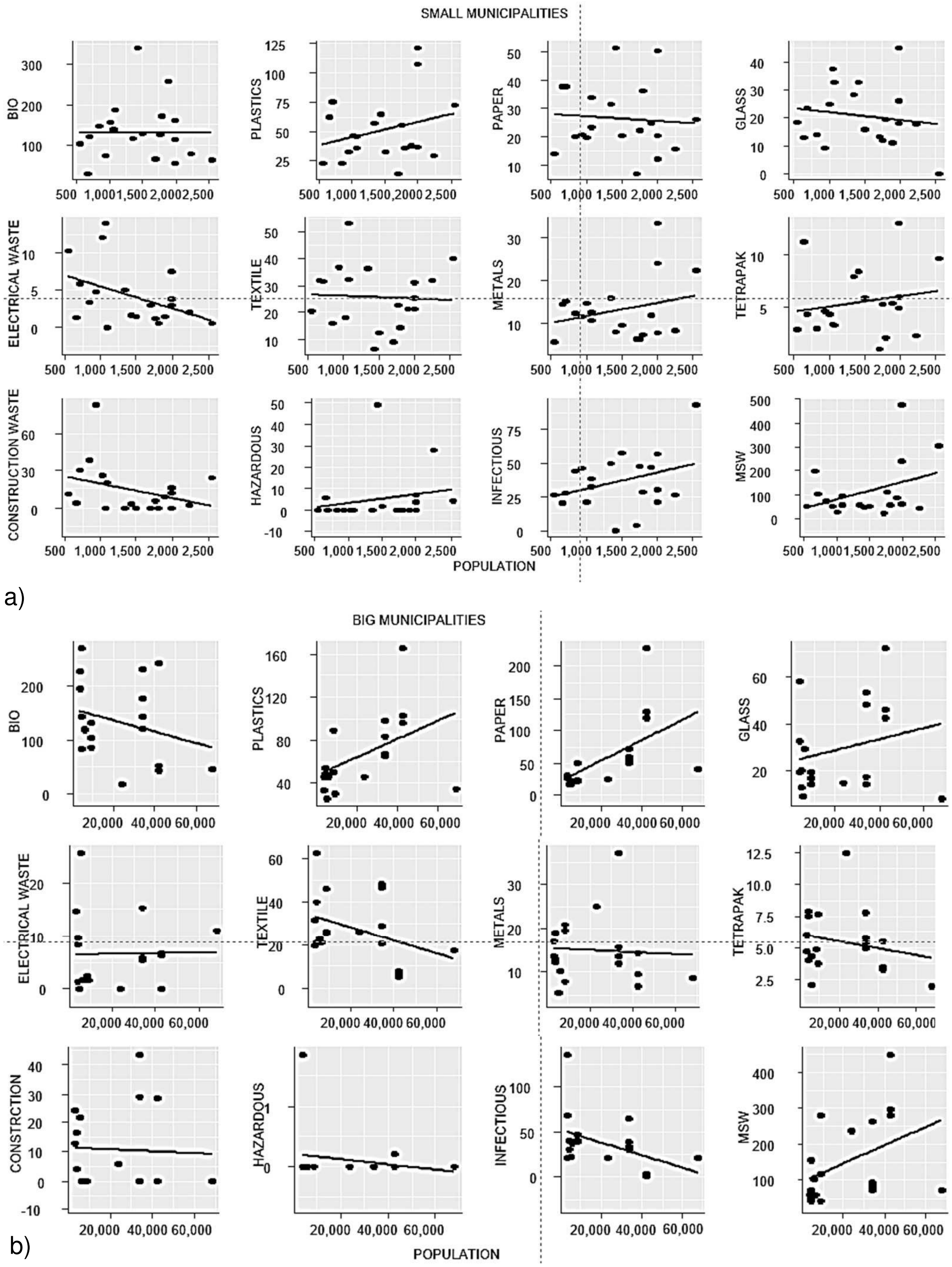

Figure 4. a) and b): Plots showing the regression between population and the amount of selected waste types. SM: hazardous waste has shown a slightly positive regression where the quantities can grow as the population grows. BM: a bigger correlation was found in the relationship between plastic and the population or paper and the population, both in the positive direction of regression, as well as MMSW and the population. Negative regression was found only in the case of infectious waste, where the amount of waste could be reduced while the population increased.

Potential in recycling

The results of the physical composition assessment also pointed out great scope for improving the sorting of municipal waste directly at source (in households), as recoverable waste disposed of in non-recyclable bins represented up to 65.7% of the MMSW. Based on the data, the approximate potential for improvement was calculated. In 2018, the MMSW production in the Czech Republic amounted to 3,732 thousand tons, i.e. 351 kg of waste per capita. Two scenarios have been developed to improve recycling rate and reduce the amount of MMSW (Fig. 4). Organic waste accounted for 27.2% of total MMSW (average for SM and BM) according to the analysis result. If we deducted all 27.2% of the MMSW that introduce organic waste, we would reach 2,715 thousand tons of MMSW per year in the Czech Republic. In addition, if we deducted additionally plastic, paper and glass from the total production, we would save 1,937 thousand tons of waste from landfilling or incineration per year. However, this scenario is less likely because we cannot reach 100% recycling of organic waste and other recyclable waste. Even though, if we improve recycling at least by 30%, this means deducting 30% of organic waste, plastics, paper and glass from the MMSW, it can save at least 305 thousand tons of organic waste from landfill and 275 thousand tons of paper, plastics and glass together every year. Fig. 4 demonstrates that even an improvement of 30% would change the amount of landfill waste and save municipal budget spending and contribute to a better environment.

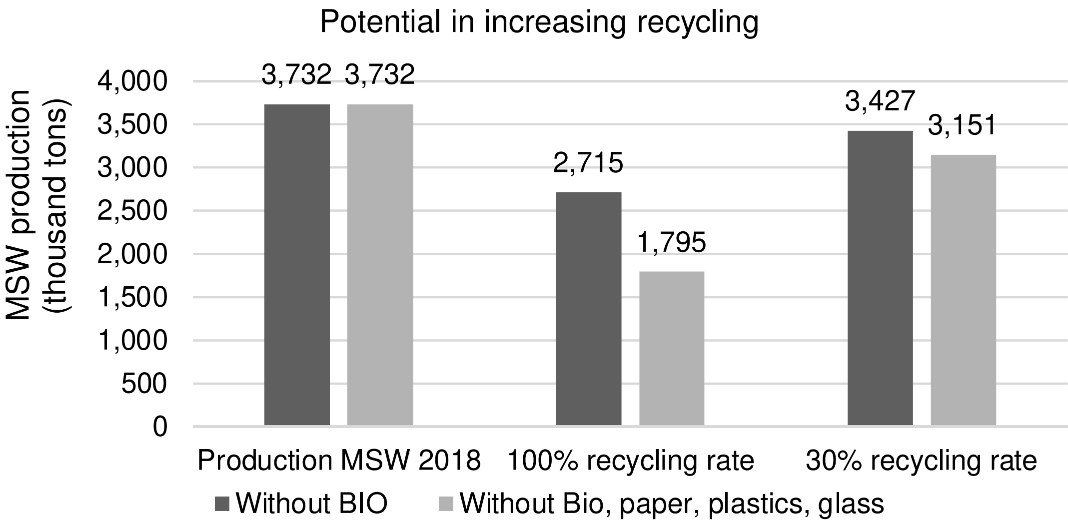

Figure 5. Possible scenario of how much MSW production would be reduced by increasing recycling. MSW 2018 means total production of MSW in 2018 in thousands of tons. MSW without BIO means how much MSW production would be reduced if organic waste that ended in MSW were recycled (removed from MSW) by 100% or 30%, specifically MSW 2018 minus organic waste, which is multiplied by the organic waste rate from the above analysis. MSW without BIO, paper, plastic, and glass means these types of waste are deducted (100% or 30%) from MSW 2018 and calculated the MSW production.

Waste discarded this way can no longer be recycled and can only be incinerated for energy recovery or, in the worst case, landfilled without any recovery. This substantial amount brings no income to the municipal authority. On the contrary, it could burden the city budget with all the tasks of collecting, maintaining and landfilling the MMSW, which means that the more MMSW it produces the higher the tax has to be paid. Therefore, the priority is to keep MMSW volume low by applying the 6R strategy: Refuse, Reduce, Reuse, Recycle, Rot and Rethink. This strategy is fundamental in the circular economy and aligns with the waste hierarchy in waste management: preventing waste generation at source (households), reusing and recycling waste treated as material and trading it means additional income to the city budget. Moreover, there is an exceptional reason calling for increased recycling at national level. Many obligations such as compulsory collection of compostable organic waste and metal waste (since 2015) and collection of gastronomic oil waste (since 2020) were introduced to municipal authorities. Czech legislation has a clear message aimed at a circular economy and waste production reduction. This seems necessary and essential to make changes not only at the municipal level, but also with the private sector. On the other hand, it is very easy to reduce the MMSW and associated costs when we have found out that there is a striking amount of recyclable waste waiting to be separated. If we redirect it, it can be saved. Study of Chotovinský et al. (2018) showed a direct impact on the amount of organic waste and paper in the MMSW. The amount of recyclable compounds in the MMSW can be easily regulated by the frequency of separate waste collection and the different collection types. In addition, the waste reduction is highly depended on the activities of the population. There are many socio-economic-technical factors that influence their behaviour and disabling them in recycling. Barrier to basic recycling are, for example, the distance and availability of recycling bins, the volume and repletion of waste bins, lack of information and education, low levels of technology and innovation, etc. (Lane & Wagner, 2013) while financial stimulus is the major motivating factor for their active participation. The good side is that it can be easily changed by the motivation and efforts of the municipal authority (Kattoua et al., 2019). The link between them and citizens needs to be strengthened. Hence, possible activities for residents must focus on the following areas: awareness raising for residents, special education activities for children and schools, organisation of recycling awareness events and overall support for reuse and recycling of waste.

Revaluing the waste collection system opens up new opportunities for the municipality. A good way is to check the data from the collection companies. Other unpublished study from INCIEN showed that many waste bins were collected practically empty or half-empty, but municipalities have to pay companies for each collection regardless of whether the bin was empty or full. Based on this information, optimizing the number of containers comes in handy and can deliver further significant budget savings that can be invested in technology, for instance. In addition, the education and motivation system can enhance public participation in many phases of waste management and help municipalities turn waste into resources.

CONCLUSIONS

Although the analysis of physical composition of MMSW is a basic tool for verifying the efficiency of sorting at source, there is a lack of comprehensive study at composition of municipal waste production in Czech municipalities. This paper executed an extensive analysis in over 30 municipalities to provide an overview on waste composition in the Czech Republic. Beside it, the study highlighted an inappropriate content in MMSW and addressed to insufficient sorting at source in households. The organic waste created almost one third of total waste sample which cannot be recycled from MMSW. The second third of waste sample was represented by other recyclable content, e.g. plastics, paper, textile, glass etc. Only the remaining one third was performed by mixed and hazardous waste. The test of homogeneity of variables displayed that the composition (proportion of waste types) of the mixed MSW was similar in both small and big Czech municipalities. The relationship between the population and waste composition was examined, but in Czech municipalities the population appeared to show positive regression only for hazardous waste and negative regression for infectious waste (slight significance). The disadvantages of low recycling rates were highlighted by their environmental, economic and social impacts on municipalities and then the identified potential for improvement. A lot of waste can be recycled as secondary materials but once it is thrown into bins for MMSW, there is no chance for it to be reused or recycled. It therefore calls for measures not only to improve sorting at source, which benefits municipal authorities, but also to adjust the municipal waste collection system with public incentive tools to improve public awareness and participation in dealing with waste.

Analysis of the physical composition of the MMSW is considered as the fundamental method by which municipal authorities verify the level of separation at source, relevantly forecast the future development and assist in the design, implementation and operation of the best practices in the waste management. It is recommended to conduct it regularly and monitor the waste production development in more municipalities over a long period of time. An idea for the future studies would be to compare the analysis of physical and chemical composition and consider their feasibility and necessity for municipalities.

ACKNOWLEDGEMENTS. Special thanks to the Institut Cirkulární Ekonomiky, z. ú. for collaborating and providing data for this study. This research was supported by the Internal Grant Agency of Faculty of Engineering, Czech University of Life Sciences Prague, Grant No. 2020:31180/1312/3108.

REFERENCES

Abdallah, M., Arab, M., Shabib, A., El-Sherbiny, R. & El-Sheltawy, S. 2020. Characterization and sustainable management strategies of municipal solid waste in Egypt. *Clean Technologies and Environmental Policy* **22**(6), 1371–1383. doi: 10.1007/s10098-020-01877-0

Abu Qdais, H.A., Hamoda, M.F. & Newham, J. 1997. Analysis of residential solid waste at generation sites. *Waste Management and Research* **15**(4), 395–406. doi: 10.1006/wmre.1996.0095

Burnley, S.J. 2007. The use of chemical composition data in waste management planning – A case study. *Waste Management* **27**(3), 327–336.

CEWEP. 2020. *Landfill taxes and bans overview*. Confederation of European Waste-to-Energy Plants, Available: <https://www.cewep.eu/wp-content/uploads/2017/12/Landfill-taxes-and-bans-overview.pdf>.

Chotovinský, O. & Altmann, V. 2017. Performance analysis of biodegradable municipal solid waste collection in the Czech Republic. *Agronomy Research* **15**(4), 1559–1570. doi: 10.15159/AR.17.009

Chotovinský, O. & Altmann, V. 2018. A comparative case study of the efficiency of collection systems for paper and biodegradable municipal solid waste. *Agronomy Research* **16**(S1), 997–1009. https://doi.org/10.15159/AR.18.106

Dahlen, L. & Lagerkvist, A. 2008. Methods for household waste composition studies. *Waste Management* **28**, 13.

Dehghani, M.H., Dehghanifard, E., Azam, K., Asgari, A.R. & Baneshi, M.M. 2009. A Quantitative and Qualitative Investigation of Tehran Solid Waste Recycling Potential. *Knowledge & Health Journal* **4**(1), 40–44, Iran, doi: 10.22100/jkh.v4i1.186

Diaz, L.F., Golueke, C.G., Savage, G.M. & Eggerth, L.L. 2020. *Composting and recycling municipal solid waste*. CRC Press, 318 pp. Available: <https://books.google.com/books?hl=cs&lr=&id=_i_gDwAAQBAJ&oi=fnd&pg=PT18&ots=JBvaoF7Qnl&sig=26mYnEN7C8iIW8p3Rpex1CkAKL4 https://books.google.com/books?hl=en&lr=&id=_i_gDwAAQBAJ&oi=fnd&pg=PT18&dq=municipal+solid+waste+calorific&ots=JBv6nz-Opl&sig=x_GvtduUeB>.

Edjabou, M.E., Jensen, M.B., Götze, R., Pivnenko, K., Petersen, C., Scheutz, C. & Astrup, T.F. 2015. Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation. *Waste Management* **36**, 12–23. doi: 10.1016/j.wasman.2014.11.009

Erami, S., Maleki, A. & Shahmoradi, B. 2015. Municipal Solid Waste Management in Mahabad Town, Iran. *ournal of Environmental Science and Technology*, 1–9.

European Commission. 2020a. *492 kg of municipal waste generated per person in the EU*. Eurostat, Available: <https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20200318-1>, [Consulted: April 9, 2021].

European Commission, 2020b. Circular Economy Action Plan for a cleaner and more competitive Europe, 28, Brussels.

Gidarakos, E., Havas, G. & Ntzamilis, P. 2006. Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete. *Waste Management* **26**(6), 668–679. doi: https://doi.org/10.1016/j.wasman.2005.07.018.

Guermoud, N., Ouadjnia, F., Abdelmalek, F., Taleb, F. & Addou, A. 2009. Municipal solid waste in Mostaganem city (Western Algeria). *Waste Management* **29**(2), 896–902. doi: https://doi.org/10.1016/j.wasman.2008.03.027

Han, Z., Liu, Y., Zhong, M., Shi, G., Li, Q., Zeng, D., Zhang, Y., Fei, Y. & Xie, Y. 2018. Influencing factors of domestic waste characteristics in rural areas of developing countries. *Waste Management* **72**, 45–54. doi: 10.1016/j.wasman.2017.11.039

Heravi, H.M., Sabour, M.R. & Mahvi, A.H. 2013. Municipal Solid Waste Characterization, Tehran-Iran. *Pakistan Journal of Biological Sciences* **16**(16), 759–769. doi: 10.3923/pjbs.2013.759.769

Kattoua, M.G., Al-Khatib, I.A. & Kontogianni, S. 2019. Barriers on the propagation of household solid waste recycling practices in developing countries: State of Palestine example. *Journal of Material Cycles and Waste Management* **21**(4), 774–785. doi: 10.1007/s10163-019-00833-5

Kern, M. & Aiwpwnkorhwn, H.-J. 2010. *Restabfallanalysen für die AWSH Abfallwitschaft Südholstein GmbH*. Available: <https://www.awsh.de/fileadmin/media/PDFs/AWK/Abfallanalyse_AWSH.pdf>

Kreith, F. 1999. *Handbook of solid waste management*. New York: McGraw-Hill, ISBN: 0070358761.

Kropáč, J., Gregor, J. & Pavlas, M. 2020. Municipal Waste Composition Analysis – Approaches to and Solutions for Czech Waste Management. In: *2nd International Conference on : Technologies & Business Models for Circular Economy: Conference Proceedings, International Conference on Technologies & Business Models for Circular Economy*, 21 May, University of Maribor, University Press, pp. 85–94, ISBN: 978-961-286-353-1, doi: 10.18690/978-961-286-353-1.8. Available: <https://press.um.si/index.php/ump/catalog/book/472>, [Consulted: April 10, 2021].

Lane, G.W.S. & Wagner, T.P. 2013. Examining recycling container attributes and household recycling practices. *Resources, Conservation and Recycling* **75**, 32–40. doi: https://doi.org/10.1016/j.resconrec.2013.03.005

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

Ma, S., Zhou, C., Chi, C., Liu, Y. & Yang, G. 2020. Estimating Physical Composition of Municipal Solid Waste in China by Applying Artificial Neural Network Method. *Environmental Science and Technology* **54**(15), 9609–9617. doi: 10.1021/acs.est.0c01802

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B. & Mensah, M. Y. 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management* **46**, 15–27. doi: https://doi.org/10.1016/j.wasman.2015.09.009

Ministry of the Environment. 2008. *Metodický pokyn ke vzorkování odpadů*. Available: <https://www.mzp.cz/web/edice.nsf/8B372EC499E277D2C125746B002F3A2A/$file/17708196.pdf>.

Ministry of the Environment. 2014. *Waste Management Plan of the Czech Republic for the period 2015-2024*. Prague: Ministry of the Environment, 189 pp., Available: <https://www.mzp.cz/C1257458002F0DC7/cz/plan_odpadoveho_hospodarstvi_aj/$FILE/OODP-WMP_CZ_translation-20151008.pdf>.

Ministry of the Environment. *Produkce a nakládání s odpady v roce 2019*, pp. 2019, Available: <https://www.mzp.cz/C1257458002F0DC7/cz/odpady_podrubrika/$FILE/OODP-Produkce_a_nakladani_2018-20191025.pdf>.

Montejo, C., Costa, C., Ramos, P. & Márquez, M. del C. 2011. Analysis and comparison of municipal solid waste and reject fraction as fuels for incineration plants. *Applied Thermal Engineering* **31**(13), 2135–2140. doi: 10.1016/j.applthermaleng.2011.03.041

Nguyen, K.L.P., Chuang, Y.H., Chen, H.W. & Chang, C.C. 2020. Impacts of socioeconomic changes on municipal solid waste characteristics in Taiwan. *Resources, Conservation and Recycling* **161**, 104931. doi: 10.1016/j.resconrec.2020.104931

Ogwueleka, T.C. 2009. Municipal solid waste characteristics and management in Nigeria. *Iranian Journal of Environmental Health Science & Engineering* **6**(3), Available: <https://www.researchgate.net/publication/40542918_Municipal_solid_waste_characteristics_and_management_in_Nigeria>.

Parfitt, J.P. & Flowerdew, R. 1997. Methodological problems in the generation of household waste statistics: An analysis of the United Kingdom's National Household Waste Analysis Programme. *Applied Geography* **17**(3), 231–244. doi: 10.1016/S0143-6228(96)00031-8

Parizeau, K., Maclaren, V. & Chanthy, L. 2006. Waste characterization as an element of waste management planning: Lessons learned from a study in Siem Reap, Cambodia. *Resources, Conservation and Recycling* **49**(2), 110–128. Idoi: 10.1016/j.resconrec.2006.03.006

Phillips, J. & Gholamalifard, M. 2016. Quantitative evaluation of the sustainability or unsustainability of municipal solid waste options in Tabriz, Iran. *International Journal of Environmental Science and Technology* **13**(6), 1615–1624. doi: 10.1007/s13762-016-0997-0

R Core Team, 2016. R: A Language and Environment for Statistical Computing. *The R Foundation for Statistical Computing, Vienna, Austria*, Vienna, Available: <http://www.r-project.org/>.

Shapiro, S. & Wilk, M. 1965. An analysis of variance test for normality (complete samples). *Biometrika* **52**(3–4), 591–611.

Talalaj, I.A. & Walery, M. 2015. The effect of gender and age structure on municipal waste generation in Poland. *Waste Management* **40**, 3–8. doi: 10.1016/j.wasman.2015.03.020

Vogel, E., Steiner, M. & Quickert, A. 2009. *Siebgestützte Restmüllanalysen im Land Steiermark.* Available: <<http://www.abfallwirtschaft.steiermark.at/cms/dokumente/10168259_4336659/4dfe9a05 /Endbericht%20Steiermark_2008.pdf>