

*Original Research*

# Who Holds the Keys to the Management of Municipal Waste and Which Locks of Municipal Sustainability do they Fit Into?

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## Abstract

Municipalities seem to be indispensable in reaching sustainability at the local level while waste management (WM) plays a crucial role. The WM system is influenced by various variables with the questionable possibility of municipal interventions. The holistic nature of the phenomena resulted in the usage of the redundancy analysis investigating 9 independent determinants and 8 dependent factors of the municipal WM simultaneously. The research was conducted on a sample of 125 municipalities from two Slovak regions, revealing 6 clusters of similarly behaving vectors. Well-defined linkages were found among spatial factors such as altitude, administrative affiliation, and presence of the marginalized groups of inhabitants or in the case of socioeconomic factors such as the number of inhabitants, fees for waste removal, and the creation of illegal landfills. Moreover, the second cluster is negatively correlated with the share of removed illegal landfills and in-house services in the WM and is almost independent of local voluntary activities in the WM and own waste recycling. Various magnitudes of the variables were observed while the number of inhabitants belong to the strongest. Thus, the research has proven that municipalities have the keys to the tools that can influence the analysed ties and support municipal sustainability.

**Keywords:** determinants of waste management, municipality, Slovakia, sustainability, waste management

## Introduction

Slovakia, similarly to other countries worldwide committed to the fulfilment of 17 sustainable development goals (SDGs) as formulated in the document *Transforming Our World: The 2030 Agenda for Sustainable Development* [1]. In the national context, the emphasis is put on 6 priority areas complying with the philosophy that sustainable development must cover three pillars of sustainability - environmental, economic, and social pillar [2]. A concrete and ambitious roadmap for implementing the Agenda 2030 is set out by the Action Plan (COM (2015) 614) which can be seen as an initial strategic document [3].

On the global scale, the analysis of the fulfilment of the commitment showed that waste management (WM) belongs to the most problematic issues [4] as its adverse effects are demonstrated not only in the environmental area [5, 6] but also in the economic [7, 8] and social one mainly in respect to poverty and health risks [9, 10].

The problems connected to waste management are more presented in the settled areas which makes the increasing volume of municipal waste a threat to sustainability [11, 12]. Municipal waste can be characterized as the waste produced by domestic, commercial, and construction activities that is collected, transported, treated, and disposed of by municipalities [13-15]. Kaza et al. [16] stated the projection that the volume of municipal waste will reach 3.40 billion tons per year by 2050 compared to 2.02 billion tons produced in 2016.

Regarding waste management in Slovakia, the biggest concerns are linked to the high rate of waste landfilling and a low rate of recycling [17]. Up to 70% of municipal waste is stored in 85 landfills [18]. In 2021, the average European citizen produced 121kg of landfilled waste per capita, while in Slovakia, it was 202 kg per capita [19]. Such volume consequently indicates a low rate of municipal waste recycling which does not only bring environmental and legislative problems in the form of landfilling of waste but also conflicts of interest in the sustainable use of landscape, economic losses, health risks, and other negative disservices [18, 20]. Impacts on biodiversity are less studied, while the inappropriate recycling of biomass from expansive weeds and invasive plants does not respect the legislation and it can be a source of propagules of these non-native plants whose ecological and socioeconomic importance in Slovakia varies [21-24], while the management of expansive and invasive plant species (including the recycling of their biomass) is demanding [25].

When talking about municipal waste management, its problems, and desired changes, the eyes are on the local level of governance - municipalities that represent the responsible body [26]. Such a setting is not unique in the Slovak environment. It can be observed for example in the USA [27], Sweden [28], Italy [29], Poland [30], and the Czech Republic [31]. However, the main reason why to focus on municipalities, instead

of on more aggregated levels, is that municipalities possess substantial autonomy when it comes to policy implementation [32] and the creation of local strategies [33].

The reasoning for the subject selection is strengthened also by taking into consideration the irreplaceable role of municipalities in SDGs' fulfilment [34, 35]. Gathering the necessary capacities, however, seems to be problematic as insufficient fiscal and legal capacities accompanied by low awareness and lack of knowledge and expertise on the local level often cause difficulties and can even lead to failure [36, 37]. Studies identified a lack of decentralization and devolution [34], lack of material support [38], lack of tools, methodologies, and data required to monitor SDGs' implementation [39] or indirect interaction between local and national level preventing longer-term and multi-stakeholder policies and programmes [40]. Additional to the state of capacities, the knowledge about behavioural patterns [41] and understanding the factors that affect waste generation [42] are of crucial importance when designing sustainable solutions.

Therefore, when identifying the determinants of municipal waste management that are aiming at contributing to the SDGs' fulfilment, we need to consider not just environmental and economic but also social, demographic, institutional, spatial, and political factors influencing a waste generation, waste treatment, and processing.

In case of factors that are influenced (thus, considered as dependent variables) on the municipal level, the following was observed: the volume of municipal waste - out of which the volume of minor construction waste and the volume of biodegradable waste (hereinafter as bio-waste) was studied, and the volume of recycled waste. This selection is rather common [8, 12, 43].

Out of managerial decisions, the influenced factors include the number of employees of the municipal office dealing with waste management [12, 44]. Another factor is the presence of volunteers or voluntary activities in the area of waste management in the municipality. A similar observation was made by Zambrano-Monserrate et al. [15], in their case, however, the variable was connected to the voluntary activities of the household's members, not the municipality as such. Though, the indication of the positive influence of voluntary activities on waste generation was apparent there, too.

Additionally, we observed the fact whether the municipality offers the services in waste management in an in-house manner or if it uses outsourcing. The dichotomy of public versus private provision appears in many works, especially in relation to efficiency. The findings, however, differ. While some studies claim that the private sector delivers more efficient results [45], others lean more towards public provision [46]. In the Czech environment, which is in many respects similar to the Slovak one, a significant effect of contracting out on cost reduction was found [37].

The last observed influenced factor was the fact whether the municipality succeed in the removal of illegal landfills (number of illegal landfills removed). This particular factor is rather unique in the Slovak conditions as there is an application developed for reporting such facts. In our opinion, this factor shows the active involvement of the municipality in waste management.

On the other side of the “equation”, there are determinants of the factors (influencing or independent variables), which can be divided into 6 areas, namely: spatial, demographic, environmental, social, economic, and political. The determinants were chosen based on their potential to influence waste generation and processing [15, 18, 32, 47, 48] and also based on the data availability (or the possibility to collect data) at the municipal level.

Within the spatial area, attention was paid to the geographical location of the municipality within the country. To a certain extent, this determinant followed the philosophy of rural-urban dichotomy [12, 15, 32]. The second determinant within this area was the altitude of the municipality which is in agreement with the conclusions of Soukiazis and Proença [32] that the characteristics of the local territory have an impact on municipal waste production. Finally, this spatial category includes the distance of the municipality from the district town, which can be seen as a spatial indication of the potential for institutional networking and the baseline for cooperation within the public administration. To our best knowledge such a determinant does not appear in the work of either Slovak or international scholars thus it can be seen as added value.

Demographic determinants, on the other hand, are frequently analysed. For this research, the total population of the municipality together with the age structure (ageing index) were considered. The findings of scholars concerning age are pointing to the direction that the elder population (65+ years old) produces less waste [41, 47] and also achieves a higher recycling rate, especially for glass and paper [15]. Some authors, however, did not find a direct influence of the age structure on waste generation [32, 49].

Out of the environmental determinants, our attention was focused on the presence and number of reported illegal landfills in the municipal territory. A similar approach can be found e.g. in the work of Kim and Kim [50], who reported the negative effects of illegal waste dumping.

When considering social determinants, the focus was on the presence of settlements of marginalised communities in the municipality or its proximity. Similar tendencies appear in the work of Stehlíková et al. [20], who associate it with a lower standard of living, higher unemployment, or a higher portion of families with more children. Similarly, significant differences in waste generation between the more and less-developed municipalities were found [32].

Economic determinants in the form of fees for municipal waste also appear frequently in studies analysing this topic. The fees influence individual behaviour regarding waste production more than social and environmental ones [18]. Fees were also declared as the most important statistically significant factor of municipal waste sorting in Slovakia [48]. Similar conclusions were made concerning Spanish municipalities [51].

The final determinant can be marked as political. It is the political affiliation of the mayor during the time of election as belonging to the political party in power or contrary to a party in opposition or being an independent candidate. A similar or the same factor has not been noted in the studied literature, however, there is an impact of local political pressures on the rate of recycling [52] or on the environmental awareness of the inhabitants [47].

Building upon these arguments, the main objective of the paper is thus to analyse spatial, demographic, environmental, social, economic, institutional, and political determinants in selected municipalities within two regions of Slovakia and their impact on waste generation, waste treatment, and processing to identify whether the Slovak municipalities do operate sufficient tools in the area of waste management to influence the SDGs' fulfilment. In the evaluated system, many dependent and independent variables operate at the same time, which had to be taken into account during the interdisciplinary and transdisciplinary investigation of municipal waste management. For this reason, we chose the most suitable direct linear multivariate gradient evaluation method (ordination), namely redundancy analysis, which is still underutilized in the analysis of social and economic parameters today.

## Material and Methods

### Characteristics of the Analysed Territory

When analysing and evaluating the issue of municipal waste management within the scope of municipal competencies, we focused on two regions of Slovakia – Nitra Self-governing Region, and Košice Self-governing Region. These regions can serve as representatives of the groups of more developed and less developed regions. Nitra Self-governing Region (hereinafter Nitra Region) belongs to the more developed regions of Slovakia and is located in the western part of the country relatively close to the capital city Bratislava. On the other hand, Košice Self-governing Region (hereinafter Košice Region) belongs to the less developed regions and is located in the eastern part of the country. The analysis comprises those municipalities from these two regions, from which we had complete data, i.e. quantification for all parameters (condition for the redundancy analysis). There were 57 municipalities from the Nitra Region

with a population of 299 397 inhabitants, which was 43.40% of the total population in the region in 2021 and 68 municipalities from the Košice Region with a population of 444 402 inhabitants, which was 56.81% of the total population in the region in 2021. In total, 125 municipalities were analysed with a population of 74 799 inhabitants, which represented 13.65% of all inhabitants of Slovakia in 2021.

The Nitra Region is located in the southwestern part of the country and it occupies 6 343.7 km<sup>2</sup> (12.9% of the area of Slovakia) (Fig. 1). The relief of the region is predominantly flat interrupted by hills. Almost the entire region is located on the Danube Hills, which is a part of the Danube Plain. In the northern part is the Tribeč mountain range. The protected landscape areas Dunajské luhy, Štiavnické vrchy, Ponitrie. Of the other small-scale protected areas, there are 11 national nature reserves, 37 nature reserves, 19 natural monuments, 57 protected areas and 9 protected bird areas [53].

The population of the Nitra Region as of 31<sup>st</sup> December 2021 was 673 547, which represented 12.4% of the total population of Slovakia with the population density of 107 inh./km<sup>2</sup> [53]. The Region is divided into 7 districts with 354 municipalities, out of which 16 have a status of town. The share of the urban population is 45.2% of all residents of the region. The registered unemployment rate in the Nitra Region as of 31<sup>st</sup> December 2021 was 4.50% which is below the national level (6.96%) [54]. In 2021, the regional GDP per capita was 14 893 EUR which is 82% of the national level [53]. In this region, 7.2% of the population was endangered by income poverty in 2020 compared to 11.4% in the whole of Slovakia [55].

The Košice Region is located in the south-eastern part of Slovakia and it occupies 6 754.3 km<sup>2</sup> (13.8% of the country) [56] (Fig. 1).

Northern and southwestern parts of the region belong to the mountainous and sub-mountainous areas. In the southeast of the territory there are floodplain forests, the eastern and southern parts have a lowland-hilly character [56]. There are 2 national parks in the territory of the Košice Region - Slovak Paradise National Park and Slovak Karst National Park, 2 protected landscape areas, 29 national nature reserves, 49 nature reserves, 23 national natural monuments, 26 natural monuments, 11 protected areas and 10 protected bird areas [56].

With a population of 802 092 inhabitants, Košice Region is the second largest in Slovakia (14.7% of the Slovak population). The average population density is 119 inh./km<sup>2</sup> [56]. The Region is divided into 11 districts and there are 440 municipalities, 17 of which have the status of town. The share of the urban population is 54.3%. The centre of the Region is Košice, which is the second-largest town in Slovakia [56].

As of 31<sup>st</sup> December 2021, the registered unemployment rate in the Košice Region was 9.98% [54], while the regional GDP per capita in 2021 reached 15 418 EUR (85% of the national level) [56]. As of 2020, there was 15.8% of the population living at risk of income poverty in the region [55].

In 2021, the total production of municipal waste in the Nitra Region and Košice Region represented 14.31% and 10.83% respectively of the total waste production in Slovakia. Together, the two monitored regions represented approximately a quarter (25.14%) of the total produced municipal waste of the Slovak Republic. Out of these



Fig. 1. Spatial division of Slovakia according to the self-governing regions (NUTS 3).

amounts, 48.24% of waste was disposed of in landfills in the Nitra Region and 31% in the Košice Region [57].

### Methodology

The area of waste management is associated with many mechanisms – dependent and independent variables. In the attempt to embrace this variety, we used multivariate analysis as it represents the only option how to correlate several parameters at once. In the case of this analysis, the number of parameters can be important. On the other hand, however, a high number of parameters can increase the possibility of inaccuracies. This type of analysis (ordination or gradient analysis) is mostly used in ecology, therefore, the highly professional ecological software Canoco 4.5 was used for the statistical evaluation of the input data (calculation of the eigenvalues), CanoDraw 4.0 for the graphical presentation (biplot creation) and WCanoImp for the data import and transformation from Excel (.xlsx) to the database format (.dta) (program producer: Microcomputer Power, Ithaca NY, USA).

Theoretical explanation of the method, as well as practical applications in ecology, is described in detail in the literature [58, 59].

From multivariate analyses, we chose redundancy analysis (RDA) since we were working with a direct response model (we distinguished between independent and dependent variables) and the relationships were linear (not unimodal). During the analysis, the input data were not transformed and the weights of the variables were not specified. Centring (standardization) was not done according to municipalities (in the ecological sense of “samples”), but according to independent variables (in the ecological sense of “species”).

Nine independent determinants were selected, which were mainly understood as influencing, and their vectors on the biplot are visualized in black. The inclusion of the determinants “fees for the municipal waste” and “presence and the amount of reported illegal landfills” was problematic, because they can be evaluated as both independent and dependent factors. The evaluated independent determinants are captured in Table 1.

Eight dependent variables were selected, which were mainly understood as influenced, and their vectors on the biplot were visualized in red. The evaluated dependent factors are shown in Table 2.

Individual exact database parameters were evaluated as of December 31, 2021, and the questionnaire survey

Table 1. The evaluated independent determinants in the Nitra and Košice Regions.

Variable	Name	Hypothesis	Expression	Source
Importance of the geographical location	Region	Waste management in different regions can have a different character due to the different natural and socio-economic conditions	Nitra Region = 0, Košice Region = 1	Administrative division of Slovakia
Distance of the municipality from the district town	Distance	Municipalities located further away from the administratively important district towns have more difficult access to institutions and some resources and therefore certain possibilities for waste management development may be limited	The distance of the municipality from the district town expressed in km	Internet platform Google Maps [60]
The average altitude of the municipality	SeaLev	Human settlements at higher altitudes have a different character, therefore the level and method of waste management can be different	In meters above sea level	The altitude of municipalities in Slovakia determined for the needs of the national legislation as amended by the Annex to Decree no. 559/2007 Coll. [61] The height above sea level of the municipality (in meters) for the municipalities of the SR and the value of the volume conversion number.
Population	Pop	The total population of a municipality can affect the scope and methods of waste management in the municipality	The absolute number of inhabitants up to the same date in the individual municipalities	Statistical Office of the SR at the internet platform DataCube [62]
Ageing Index	Age	The age composition of the population can influence the attitudes and behaviour of the population in waste management	The number of people in the post-productive age over 65 years to the people in the pre-productive age 0 to 14 years	Statistical Office of the SR at the internet platform DataCube [63]

Table 1. Continued.

Presence of the marginalized communities in the municipality	Marg	Socially disadvantaged groups of people on the periphery of the majority society may have different social and environmental habits than the majority population, therefore their behaviour may affect some parameters of waste management	Share of Roma population on the total population in the municipality in %, expressed in the following intervals: 1-10%, 11-20%, 21-30%, 31-40%, 41-50%, 51-60%, 61-70%, 71-80%, 81-90%, 91-100%)	Ministry of Interior of the SR [64]
Fees for the municipal waste	WastPay	The difference in the amount of fees for waste management in a municipality can affect the behaviour of residents of the individual municipalities in waste management	Fees in euros per inhabitant per year	Generally binding regulations of the municipalities are completed through electronic communication with representatives of the municipality
Presence and the amount of reported illegal landfills	Illeg	Illegal landfills can be a measurable cause-and-effect environmental indicator for public administration, which has financial, health, and other implications	Number of illegal landfills	Internet platform TrashOut [65]
Political affiliation of the mayor	Policy	The mayor of the municipality may have easier access to some forms of help (better communication channel, lobbying, or even corruption) if he/she has closer contact with the ruling political party	In how many of the last two four-year election periods did the mayor run for the ruling political party, expressed as 2, 1 or 0	Statistical Office of the SR at the platform volby.statistics.sk [66]

Table 2. The evaluated dependent factors in the Nitra and Košice Regions.

Variable	Name	Hypothesis	Expression	Source
Amount of the produced waste	Waste	The amount of waste produced in the municipality is (also) influenced by the independent variables mentioned above	Tons per 1 year in the municipality	A questionnaire filled out by the municipalities
Construction waste	Constr	The amount of construction waste produced in the municipality is (also) influenced by the independent variables mentioned above	Tons per 1 year in the municipality	A questionnaire filled out by the municipalities
Amount of the registered bio-waste	BioW	The amount of produced and registered bio-waste in the municipality is influenced by the dependent variables mentioned above. Note: Part of the bio-waste is not registered due to the local composting in the yard, feeding to animals, etc.	Tons per 1 year in the municipality	A questionnaire filled out by the municipalities
Employees in the waste management	Staff	Employment in the municipality in the area of waste management is influenced by the environmental conditions	The absolute number of municipal office employees in the waste management	A questionnaire filled out by the municipalities
In-house services in the waste management	Serv	The securement of in-house services in waste management is the result of local conditions and economic possibilities of the municipality	Whether the main measures in waste management are secured by the in-house provision, e.g. waste collection, operation of the collection yard, etc., evaluated as yes - 1 or no - 0	A questionnaire filled out by the municipalities
Own recycling of waste	Rec	Recycling is a legal form of waste management and its local provision is a response to the socioeconomic environment of the municipality	Whether or not there is an arbitrary own system of local waste recycling and recovery, evaluated as yes - 1 or no - 0	A questionnaire filled out by the municipalities

Table 2. Continued.

Local voluntary activities in the waste management	Volunt	Volunteer activities are generated by certain problems and by awareness of local communities	Whether or not such activities occurred in the researched period, evaluated semi-quantitatively, yes - 1 or no - 0	A questionnaire filled out by the municipalities
Share of removed illegal landfills	IllegR	Removal of illegal landfills is also influenced by the independent variables of environmental conditions	Percentage of detected removed illegal landfills from all identified and registered illegal landfills, while in the case that illegal landfills were not detected in the cadastre of the municipality, the status is evaluated neutrally as 0	Internet platform TrashOut [65].

of other indicators was conducted in the period from September 1 to December 31, 2021.

extent of 87.8% of the expressed variance (58.9% for the x-axis and 28.9% for the y-axis).

### Results and Discussion

In the multivariate evaluation of the results (redundancy analysis), the accuracy of the details is decreasing with an ascending number of factors. On the other hand, the main trends remain, which is sufficient for the interpretation of the fundamental correlations. The evaluated links between the indicators apply to the

### Independent Determinants

In the first part of the research, we evaluated the independent variables, i.e. the “influencing” determinants, which form the basic conditions and driving forces of the investigated processes and usually do not result directly from the management and measures of the public administration. They were evaluated from the biplot shown in Fig. 2 (vectors

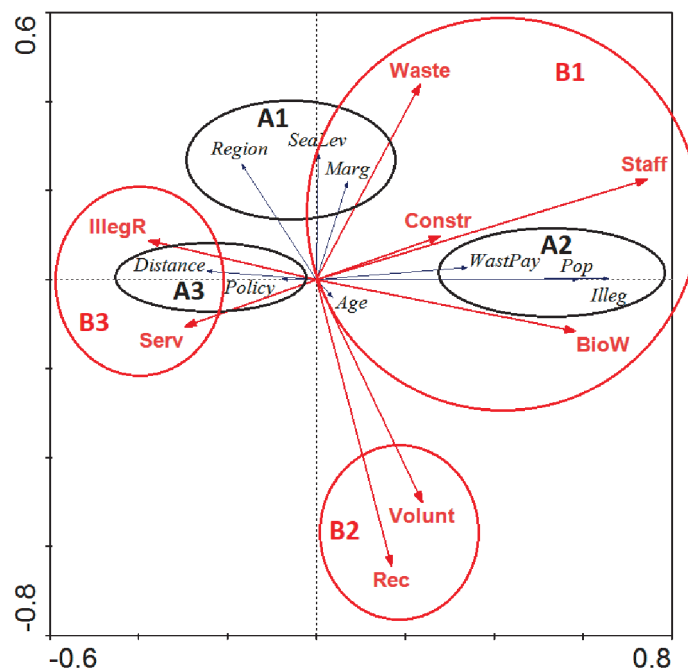


Fig. 2. Redundancy analysis of correlations between the selected quantified vectors of waste management in the Nitra Region and Košice Regions in Slovakia in 2021.

Legend: independent determinants are marked in blue: the importance of geographical affiliation – *Region*, distance from the district town – *Distance*, average altitude of the municipality – *SeaLev*, population – *Pop*, aging index – *Age*, presence of marginalized groups in the municipality – *Marg*, fees for the municipal waste – *WastePay*, presence and amount of the reported illegal landfills – *Illeg*, political affiliation of the mayor – *Policy*; dependent factors are marked in red: amount of the produced waste – *Waste*, construction waste – *Constr*, amount of the registered bio-waste – *BioW*, employees in the waste management – *Staff*, in-house services in the waste management – *Serv*, own recycling of waste - *Rec*, local voluntary activities in the waste management – *Volunt*, share of removed illegal landfills – *IllegR*; A1-A3 and B1-B3 – clusters, see in the text).

of independent variables are shown in blue). The very different length of the vectors implies that different variables have different strengths in the described correlations.

The independent determinants create three well-defined clusters, within which the determinants are synchronized, which means that they behave comparably (their values change comparably under the same conditions).

Within the first group of determinants (A1), altitude, geographic/administrative affiliation, and the presence of marginalized groups are relatively strongly correlated. Hereby, the findings provide supporting evidence for the stated hypotheses. The explanation of the phenomenon could be that in the Košice Region, less developed municipalities with the presence of marginalized groups have higher altitudes, while in the Nitra Region, the situation is the opposite. Higher altitude often indicates remoteness which can get reflected in the cumulation of issues in those municipalities that are at the periphery of institutions' outreach. Hence, in the case of municipalities with higher altitudes, their ability to improve the waste management situation is jeopardized.

Even though this is not a factor that can be directly modified by the managerial decision of the municipality, higher attention should be paid to such municipalities to reverse or at least minimize this threat. The report of the United Nations [67] assigned this role to the national government, which can apply transformative policies and contribute to increased equality and resilience.

Regarding the second group of determinants (A2): population, the number of illegal landfills, and waste fees are well correlated and almost independent of the previous cluster as the angle between this cluster and the first cluster is more or less a right angle. Within this group of determinants, we could observe that the larger the number of inhabitants in the municipality, the greater the number of illegal landfills (a very strong statistical correlation). Such a relation is in line with our hypotheses, furthermore, it seems logical, since more inhabitants form a more heterogeneous critical mass with different behavioural patterns. To a certain extent, this relationship can be influenced by the policies adopted by the municipality, especially in the case of creation of the illegal landfills. Environmental awareness of inhabitants supported by campaigns, promotions, or a mayor who promotes environmental policies and measures has been proven to influence waste generation and increase the level of environmental protection.

Another strong relationship can be seen in the case of the fees for waste and the total population where the larger the municipality, the higher the fees for waste. During the hypotheses design, we assumed that the fees will have an impact on behaviour which is partially justified by belonging to the same cluster as the emergence of illegal landfills. Furthermore, the relationship between the fees and population was expected as in the Slovak conditions the fees for waste are depending on the amount of waste that is disposed

of in landfills. Generally, the eradication of disposal of waste in landfill should be an aim of each municipality. This can be done by using innovative technologies and resource-saving methods of disposal.

Additionally, the fees for waste are inevitably influenced by the increasing energy prices, while the smaller municipalities are usually more careful and slower in the reflection of the actual situations in the local fees and taxes. Hereby, especially in the case of the first reason, even the larger municipalities can act proactively and adopt measures for supporting recycling, for example via increased managerial expertise and investments in modern and more productive equipment.

Compared to the previous determinant, however, the correlation of waste charges was less significant (short vector), which can be explained for example by the greater dispersion of the data.

The third cluster (A3) is formed by two weaker determinants (distance from the district town and the political affiliation of the mayor), which are negatively correlated with the previous cluster (they have the opposite direction of the vector). It, therefore, applies that the further the evaluated municipality is from the district town, the smaller the number of inhabitants and the more significant the factor of the mayor's political identity. It is an interesting insight indicating that while larger municipalities (bigger rural villages or small towns) manage the area of waste benefiting from their size (favourable personnel and financial capacities), the situation of smaller and more distant municipalities is easier only if they have a mayor with a favourable political orientation. The more advantageous situation of the larger municipalities or municipalities located closer to the institutional centres can be explained, among others, by reaching economies of scale.

Regarding the political orientation, we expected that mayors with an affiliation with a ruling political party would have more successful waste management due to the assumed better access to financial resources and other support mechanisms as declared by Transparency International Slovakia [68]. This hypothesis, although statistically measurable, was confirmed only to a small extent.

The ageing index remained aside from the main three groups. It is an independent player with very weak ties to the entire system (the shortest vector and large angle with other factors), most strongly (but not significantly) correlated with the municipality size cluster. This result shows that waste management is not significantly influenced by the age of residents and thus by bad long-term habits or lower acceptance of new trends. This can result from the fact that measures must be respected by all residents regardless of age.

### Dependent Factors (Management and Impacts)

In this part, we correlate the factors that are directly or indirectly dependent on the determinants listed



in the previous subsection (blue vectors with the red ones in Fig. 2).

The biplot of correlations shows that the strength of the dependent variables is more balanced (smaller variance in the length of the vectors). The apparatus of relationships is most strongly influenced by the number of employees in waste management in the municipality and the indicators of recycling. Hereby, we can also observe three clusters.

The first group of factors (B1) includes the amount of generated municipal waste, minor construction waste, bio-waste (this is the weakest), and the number of municipal employees working in waste management. The results are in line with experience proving that the different types of waste behave comparably – a higher amount of municipal waste also means more of the other types of waste. Interestingly, there is a stronger correlation between municipal waste and construction waste than with bio-waste, which may be caused by the alternative forms of bio-waste processing that are not included in the study (home composting, feeding to animals, burning, etc.).

Further, we can observe that the larger municipalities produce more waste (applies to all three types of assessed waste) and the amount of waste produced is also related to the number of illegal landfills. This means that a larger municipality has a greater number of illegal landfills. The finding is consistent with the observations of other authors (as described above) and also with the hypotheses, but the statistical proof was lacking.

When it comes to the number of municipal employees, it also depends on the amount of waste. This relationship is not surprising as a bigger municipality means more waste but also a greater organizational structure with a higher number of employees. Such organization often indicates increased specialization allowing better expertise of the employees in the field and perhaps leading to increased efficiency [69]. On the other hand, there is a fragile balance between greater expertise and wasting resources typical for bureaucratic structures. Therefore, municipalities should make conscious and well-informed decisions when organizing waste management as the organizational structure belongs to their exclusive competencies.

The second group of factors (B2) consists of recycling and voluntary activities, the vectors of which form almost a right angle with the previous factors, i.e. they are more or less independent of them. In other words, whether the waste management is supported by effective recycling or volunteers does not depend on the number of inhabitants or the amount of waste produced. Such findings are not fully in line with the formulated hypotheses where we assumed the relationships between socioeconomic situation and recycling and the relationship between voluntary activities and emergence of the environmental problems.

The analysis shows that inhabitants in municipalities that are recycling more have also a higher tendency to get involved in voluntary activities. Additionally,

a measurable correlation with bio-waste was also observed (the sharpest angle between the visualised vectors). This might indicate that bio-waste is the easiest to recycle while the volunteers can contribute. It is noteworthy that recycling and volunteering are negatively correlated with the geographic-administrative affiliation of the municipality. In redundancy analysis, a negative correlation does not mean a zero correlation, but a strong relationship, where an increase in one factor means a decrease in another factor. In this case, the interpretation could be that “the more the Region is Košice (Nitra Region = 0, Košice Region = 1), the higher the altitude and the more marginalized groups, the fewer volunteers involved and the lower the level of recycling”.

This might be linked to the level of environmental awareness in these municipalities which on the one hand seems to be independent of the municipality size, thus, in this respect, small municipalities can also reach satisfactory results. On the other hand, the situation is worse in the municipalities with the presence of marginalized groups. In both cases, communication with inhabitants about the importance of this topic could be an effective tool in the hands of local self-governments that are in charge of the communication strategy. The communication strategy, however, must be well embedded in the knowledge about the local conditions and adjusted to the recipients. Furthermore, the role of the municipality is to provide informal education to the inhabitants and contribute to awareness raising via active campaigns about the topics or via active and involved self-government representatives (the mayor or members of the municipal council).

The third group (B3) includes two factors – in-house provision of services in waste management and removal of illegal landfills. Findings within this group justify the reasoning indicated in the hypotheses only partially. They are well correlated which brings a new insight since they are independent of voluntary activities (right angle between the vectors) and they are negatively correlated with the size of the municipality and with the amount of all types of waste.

It is, thus, possible to conclude that the larger the municipality, the smaller the proportion of illegal landfills removed (perhaps because they are more frequent and larger). However, they are positively correlated with the distance from the district town, meaning that the small municipalities further away from the district town remove illegal landfills more successfully. Furthermore, it indicates that even though small municipalities are not benefiting from the economy of scale, they can be more proactive and flexible when it comes to dealing with local issues despite their distance from the district authorities. A possible explanation could be that there are fewer illegal landfills and the potential fines for non-compliance with the law would be seriously affecting their financial conditions.

Additionally, in-house provision of services in waste management works as a supporting factor, too. This model of service provision seems to be beneficial

especially for small municipalities, in terms of their increased flexibility when dealing with the illegal landfills.

Since the arrangement of public service provision at the local level is solely in the hands of local self-governments, they can adopt appropriate measures in the name of sustainability.

We would like to add that although the political affiliation of the mayor is not a strong indicator (short vector), it is well correlated with the removal of illegal landfills.

### Discussion

The conducted analysis revealed that there are several independent determinants and dependent factors of different natures that can influence the situation in waste management at the local level in Slovakia. The chosen approach places the known information in a new context and offers unique optics that can be seen as the main added value of the research. On the other hand, this fact also means that confrontation and comparison of the findings with other studies hits limitations.

Within the analysis, six clusters of mutually interlinked factors and determinants can be identified. In the case of the independent determinants, the main findings include the fact that population, number of illegal landfills, and waste fees are closely related. Talking about the population and illegal landfill creation, Kinnaman and Fullerton [70] observed the patterns of illegal landfill creation in relation to population density. They associated it with areas where population density is very high or very low: urban areas with commercial dumpsters and rural areas with remote spots for dumping. Additionally, the mere number of inhabitants has been previously indicated as a determinant of eco-efficiency in municipal waste services [71, 72]. Contrarily, the analysis conducted in the Slovak environment proved that smaller municipalities with a lower standard of living and a lower level of waste sorting are minimally active in improving waste management [48]. Additionally, the small and further located municipalities are often unable to provide the services at the desired qualitative level or for reasonable per-unit costs. Contrary, in larger municipalities, the transaction costs tend to increase much slower with municipality size and economies of scale can be exploited [69].

When it comes to the relationship between fees for waste and illegal landfills, there seems to be a fragile balance. Kinneman and Fullerton [70] observed that introduced or increased fees for waste lead to the creation of illegal landfills. According to Macias and Piniarski [73] for the elimination of illegal landfills, the fees should stay unchanged. The positive impact of fee introduction on illegal landfill creation was reported in the case of the deposit-refund system [74]. In Slovakia, lower fees are paid in those municipalities

that dispose of less waste in landfills and recycle more [75]. According to the Slovak Municipal Association [76], smaller municipalities (rural villages) dispose of smaller amounts of waste in the landfills as they can process more waste in other ways (burning or handing over in case of paper, using in the household via composting or animals feeding in case of bio-waste, etc.).

Another important finding shows the relationship between the distance from the district town and the political affiliation of the mayor and these are negatively correlated with the number of inhabitants. The research revealed that if the benefit of proximity is missing, it is partially substituted by the political affiliation of the mayor. The literature contains only limited evidence on the importance of political affiliation and it is rather about a standpoint towards the political ideology – e.g. the more votes for left-wing parties, the better eco-efficiency in waste management [77]. This area thus provides an opportunity for further investigation.

Within this section, observation was made also about the insignificant influence of the age of residents on waste management. Similar findings occur in the studies of Soukiazis and Proença [32] in Portugal municipalities, Romano et al. [72] in Tuscan municipalities (Italy), and Lebersorger and Beigl [49] in German municipalities. In Slovakia, Slučiaková [47] concluded that the older population (65+) is positively correlated with the recycling rate, especially in the case of paper and glass. Such a result is supported also by Zambrano-Monserrate et al. [15] studying developing countries.

Contrary findings were reported by De Jaeger et al. [77] who pointed out that the specific consumption patterns of some age groups (less than 4 and more than 75 years old) can lead to higher residual municipal waste generation.

In the case of the dependent factors, the analysis revealed that the larger the size of the municipality, the more produced waste and also the higher the number of employees in waste management. This association is only a rational consequence as in absolute terms more people produce a higher amount of waste and more populated, bigger, municipalities have usually a denser organizational structure. On the other hand, there must exist a “stopping point” for the number of employees since more employees for the same amount of waste indicates lower efficiency and hampers sustainability [12].

Another important finding indicates the relationship between recycling and the involvement of inhabitants in volunteering activities. These factors are independent of the municipality size and negatively correlated with the presence of marginalized groups in the municipality which more frequently occurs in the Košice Region.

When analysing factors influencing recycling and involvement in voluntary activities, prior studies include mainly the income and education level of inhabitants [32, 78]. Additionally, Zambrano-Monserrate et al. [15] found that there is a greater probability that

a family practices solid waste source separation when the household head volunteers for this type of activity. Also, Šedová [79] confirmed a positive impact of income and education on the rate of illegal waste dumping.

This study indicates that recycling and volunteering in waste management can be considered as activities mostly presented in communities with a higher level of development and increased environmental awareness. According to Hrabovská [80], such communities produce a higher volume of waste but also reach better results when it comes to waste utilization. On the other hand, our findings are in contrast with Taušová et al. [18] who claimed that more developed regions in Slovakia have the lowest recycling rates.

The last observed cluster showed the relationship between the in-house provision of services in waste management and the removal of illegal landfills. Furthermore, these two are independent of voluntary activities and negatively correlated with the size of the municipality and with the amount of produced waste. In-house provision of services in waste management thus seems to be more effective when it comes to dealing with local problems (illegal landfills removal), especially in the case of small municipalities. In the prior studies, it has been proven that contracting out (as opposed to the in-house provision) does not work well in small municipalities [69, 81, 82] mainly because their size does not allow for a reduction of the unit costs [83] and also because small municipalities lack the negotiating power and skills to conclude beneficial contracts with private providers [82]. On the other hand, aspiring for the economy of scale is quite frequent advice in the literature (e.g. [77, 81, 84]) that encourages small municipalities to enter into inter-municipal cooperation [69, 82, 85]. In the Slovak conditions, however, contracting out is the dominant mode of service provision [86].

The conducted analysis showed that in the case of almost all clusters formed by the interlinked determinants and factors, those are municipalities that can influence the situation towards increased sustainability. Several instruments can be used. Communication tools in the form of communication strategies, campaigns, and promotion of environmental policies and measures together with the promotion of informal education and active involvement of local representatives form the first group. Their positive impact was reported e.g. by [47, 87]. These all are aiming at increasing the environmental awareness of inhabitants. To a certain extent, municipalities in Slovakia understand the importance of their communication which is confirmed by Bačík and Klobučník [88], who stated that almost all municipalities operate their websites or are active on social media. The importance of communication tools for municipalities was also highlighted by Bumbalová et al. [89].

Secondly, the municipalities are in charge of local waste management policies when they can employ innovative technologies and resource-saving methods of disposal, e.g. using the waste through reasonable

recycling of resources or building a waste-free circular economy [90]. De Jaeger et al. [77] indicated also the reversed logic that the political desire for more waste reduction is accompanied by improved managerial expertise or investments in modern and more productive equipment.

These measures are highly dependent on the level of expertise of local representatives. The importance and positive impact of the expertise on the effectiveness were reported e.g. by De Jaeger et al. [77], Tang et al. [91], and Struk and Bakoš [69].

Professional and well-informed staff at the local level are also necessary in the case of the last two tools in the municipal hands. Those are the organizational structure of waste management including competencies and the way of service provision that is applied in the municipality. The importance of the organizational structure for the efficiency of local services was declared for example by Bel et al. [92]. The form of the service delivery is often a subject of scientific studies while authors agree with in-house provision being more effective and efficient for the small municipalities [72, 81], however, they are also often promoting inter-municipal cooperation as a way how to deal with the disadvantages of the smaller size [69, 83, 85] and many others. Inconclusive findings about this topic, however, also occur, while Soukopová et al. [37] can serve as an example.

## Conclusions

Waste management in regions and individual municipalities has many aspects, while this area is mostly explored from an economic and environmental point of view. However, the integrated, transdisciplinary analysis of waste management supported by a wide spectrum of gradient-evaluated parameters is, in the form we present it, innovative and pioneering.

The selected redundancy analysis revealed several new connections that operate in the multivariate system of waste management. It showed that the factors that influence the course of waste generation and waste management create statistically definable clusters of similarly behaving vectors. The groups of spatial factors (altitude, administrative affiliation of municipalities, and distribution of marginalized groups) and socioeconomic factors (number of inhabitants in the municipality, amount of fees for waste removal, and creation of illegal landfills) are well defined. If we were to generalize our research results, then for the evaluation of comparable regions it would be enough to select only a small number of factors from both mentioned groups and we would be able to predict the increase or decrease in the values of other factors from these groups.

The impact and response factors that are interesting for the activity of the public administration are also clustered in a similar way such as the generation of various wastes that has the same trend direction,

e.g. more mixed municipal waste usually means more construction waste and bio-waste and, secondarily, more employees in waste management. On the other hand, the activities of volunteers in waste management and recycling are almost independent of the previous clusters, which appears to be a surprising finding. The political affiliation of the mayor and the age of inhabitants are vectors with weak interactions.

The strength of the factors influencing the course of the processes is, however, not the same (even if their trends can be determined relatively well) and the parameters of the factors in different environments can vary in different degrees. Therefore, further studies should be focused on a wider verification of the reliability of the algorithms we have created in other regions or countries.

Even at this stage of research, the results of the analysis provide the possibility of creating management measures in packages (modules) with well-defined groups of factors characterized by the same trends and links. This could facilitate integrated waste management performed by municipalities and more systematic creation of local and regional strategies for sustainable and in some contexts innovative, waste management. The majority of the revealed relationships can be tackled via the communication strategies of municipalities or the expertise of staff employing solutions tailored to the local situation. Since these approaches are under the direct supervision of municipalities in Slovakia, we can confirm their ability to influence the WM on the pathway towards municipal sustainability.

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### Conflict of Interest

The authors declare no conflict of interest.

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