Efficiency and sustainability in municipal waste management: A comparative study of five rural municipalities in Slovakia

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ABSTRACT

The aim of this study was to analyze and evaluate the development of separate municipal waste collection and the financing of waste management in five selected villages (Bánov, Komjatice, Svodín, Svätý Peter, and Trnovec nad Váhom) within the Nitra Self-Governing Region during the period 2018–2023. The results indicate that, on average, the villages incurred annual waste management costs of €98,660, corresponding to €31 per inhabitant. Despite generating annual revenues averaging €66,734 (€21.40 per inhabitant), the economic balance remained negative, with an average deficit of €31,926 (€9.60 per inhabitant). These findings suggest that although progress has been achieved in waste sorting and cost recovery, further improvements are necessary – particularly in reducing financial deficits and enhancing sorting efficiency – to meet and exceed European waste management targets. The trends observed in the Slovak Republic are consistent with findings from international studies, which confirm that the volume of municipal waste tends to increase alongside rising living standards. At the same time, waste separation rates have also improved, largely as a result of supportive legislative frameworks in the Slovak Republic.

Keywords: municipal waste, waste separation, waste management, economic efficiency, sustainably.

INTRODUCTION

One of the major challenges in waste management in the Slovak Republic is to halt the continuous increase in waste generation, reduce the high proportion of landfilling, and significantly improve the rate of waste separation. An optimally functioning municipal waste separation system at the local level should minimize the financial burden on residents while simultaneously creating the necessary conditions for achieving legally mandated separation targets. To meet these goals, it is essential to continuously improve municipal waste management systems under the responsibility of local governments, ensuring they address the needs of all relevant stakeholders. Key priorities must include cost-effectiveness, compliance with applicable waste management legislation, and the protection of the environment [Báreková et al., 2011; Báreková, 2014; Báreková et al., 2020].

These goals must align with the national legislative framework, particularly Act of the Ministry of Environment SR no. 79/2015 Coll. on Waste and related implementing decrees of the Ministry of Environment SR (No. 365/2015 Coll., 366/2015 Coll., 367/2015 Coll., 371/2015 Coll., 372/2015 Coll., and 373/2015 Coll.). Together, these legal instruments provide the foundation for establishing sustainable, efficient, and legally compliant waste management systems that prioritize long-term environmental protection.

The main objective of this study was to analyze and evaluate the development of separate municipal waste collection and the financing of waste management in five selected municipalities – Bánov, Komjatice, Svodín, Svätý Peter, and

Trnovec nad Váhom – located in the Nitra Self-Governing Region during the period 2018–2023.

MATERIAL AND METHODS

Characteristics of the monitored municipalities

The villages of Bánov, Komjatice, Svodín, Svätý Peter, and Trnovec nad Váhom are all located in the Nitra Self-Governing Region in southern and southwestern Slovakia. These villages were selected for analysis based on their location within agriculturally and environmentally significant lowland regions and their comparable population sizes, ranging between 2.000 and 5.000 inhabitants (Table 1) [Statistical Office of the Slovak Republic, 2025].

Village of Bánov is situated at an elevation of 121 meters above sea level and is part of the Nové Zámky District. The municipality lies within the Danube Lowland, specifically in the warmest and driest climatic region of the Slovak Republic. It covers a total area of 1.676 hectares. The most important watercourse in its cadastral territory is the Nitra River [PESD of the village Bánov, 2015–2023].

Village of Komjatice is located in the northwestern part of the Nové Zámky District in the western portion of the Nitra Region. The municipality is situated on floodplains formed by historical branches of the Nitra River and flat loess terraces. The territory is characterized by fertile soils, including floodplain, alluvial, and black soils. The central built-up area lies at an altitude of 128 meters above sea level, and the cadastral area spans 3.076 hectares [PESD of the village Komjatice, 2015–2023].

Village of Svodín lies in the Danube Plain, on the eastern foothills of the Pohronská pahorkatina (Pohronská Hills), in the southern part of the Nitra Region. The Dobra River flows through the municipality. It has a total area of 5.348 hectares, and the altitude at the center is 193 meters above sea level. From a hydrological perspective, the municipality belongs to the Hron River basin [PVD of the village Svodín, 2024–2030].

Village of Svätý Peter is located at 138 meters above sea level and covers a cadastral area of 3.433 hectares. The municipality lies in the Danube Plain, on the southwestern edge of the Pohronská pahorkatina. The narrow, deforested cadastre extends to the marshy floodplains of the Nitra and Žitava Rivers. Hydrologically, the area belongs to the Váh River basin [PESD of the village Svätý Peter, 2021–2027].

Village of Trnovec nad Váhom is situated in the southwestern part of Slovakia, within the Šaľa District of the Nitra Region. It lies on the eastern edge of the Danube Plain, along the left-bank embankment of the Váh River. The built-up area is located at 115 meters above sea level [PESD of the village Trnovec nad Váhom, 2016–2020].

Data collection and processing

To collect the necessary data for the study, a structured approach consisting of several key steps was followed. First, relevant information was obtained through both personal and e-mail communication with employees of the Municipal Offices in the selected municipalities. Second, the geographical and environmental context of the studied areas was characterized. Third, municipal waste generation and the quantities of sorted waste fractions – specifically paper and cardboard, glass, plastics, and metals/metal packaging – were calculated and expressed in kilograms per capita. In addition, total costs, revenues, and the economic result per capita in euros were calculated. The methods of analysis, synthesis, and comparison were applied throughout the data processing phase.

Statistical analysis

Statistical analyses were performed using STATISTICA version 13.1. Correlation analysis

Table 1. Number of inhabitants in monitored villages in the Nitra Self-Governing Region for the years 2018–2023

Year	2018	2019	2020	2021	2022	2023
Bánov	3 719	3 703	3 672	3 645	3 603	3 582
Komjatice	4 294	4 292	4 277	4 230	4 210	4 197
Svodín	2 471	2 477	2 468	2 401	2 374	2 370
Svätý Peter	2 793	2 782	2 766	2 705	2 712	2 708
Trnovec nad Váhom	2 716	2 703	2 692	2 769	2 773	2 775

and principal component analysis (PCA) were conducted. The variables included in the PCA were costs per capita (€), economic result per capita (€), fees for waste management (€/capita), mixed waste (%), revenues per capita (€), waste production (kg/inhabitant), and waste sorting rate (%). Statistical significance was set at $p \leq 0.05$ for all tests.

Evaluation framework

To compare the selected municipalities, average per capita values calculated over the six-year observation period (2018–2023) were utilized. The evaluation of waste management (WM) efficiency and sustainability was based on the framework developed by Kiko (2023) and included the following indicators:

Municipal waste generation rate
a) Average amount of municipal waste generated-per capita (kg/inhabitant).

Municipal waste sorting rate
a) Average sorting rate of municipal waste expressed as a percentage per capita over the six-year period.

Financial indicators
a) Average expenditures in EUR per capita.
b) Average revenues in EUR per capita.
c) Average financial balance in EUR per capita.

Sorted waste commodities
a) Paper and cardboard – average amount in kg per capita.
b) Glass – average amount in kg per capita.
c) Plastics – average amount in kg per capita.
d) Metals/metal packaging – average amount in kg per capita.

Each indicator was evaluated using a performance-based scoring system. The municipality with the best value in a given indicator received 5 points, while the lowest-performing one received 1 point. The final score for each municipality was calculated as the sum of all points awarded across the evaluated indicators.

RESULTS AND DISCUSSION

Overall, the municipality of Trnovec nad Váhom consistently recorded the highest levels of municipal waste (MW) generation across all monitored years, ranging from 399 to 551 kg per capita. Conversely, the lowest MW generation was observed in the municipality of Svodín, with values between 209 and 447 kg per capita. Notably, in 2021, the villages of Bánov, Komjatice, and Trnovec nad Váhom exhibited peak MW production relative to other years, a trend that may be partially attributed to the impacts of the COVID-19 pandemic (Figure 1). The average MW generation over the entire observation period was highest in Trnovec nad Váhom, reaching approximately 497 kg per capita. This was followed by Komjatice (400 kg), Bánov (391 kg), and Svätý Peter (382 kg per capita). In contrast, Svodín recorded the lowest average MW generation, at 326 kg per capita.

The highest municipal waste separation rate during the monitored period was observed in the municipality of Trnovec nad Váhom, with steadily increasing values ranging from 57.65% to 65.70% (Figure 2). In contrast, the municipality of Bánov recorded the lowest separation rates in 2018, 2019, 2020, and 2022 compared to the other municipalities. The villages of Komjatice, Svodín, and Svätý Peter exhibited a generally
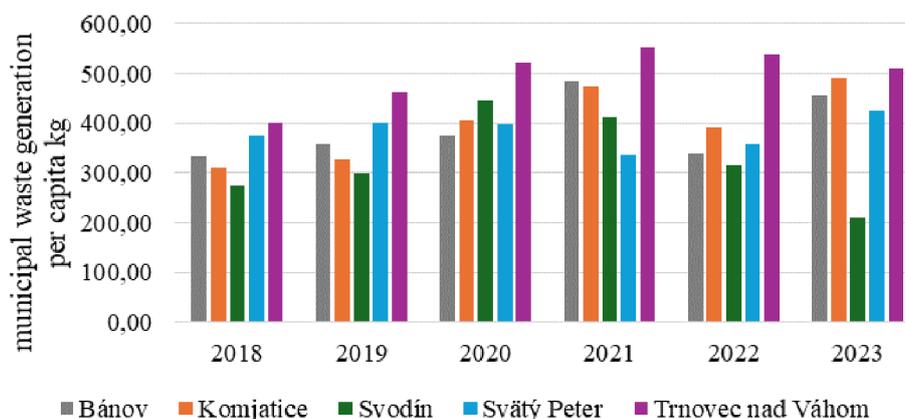

Figure 1. Trends in municipal waste generation per capita (kg) in the monitored villages
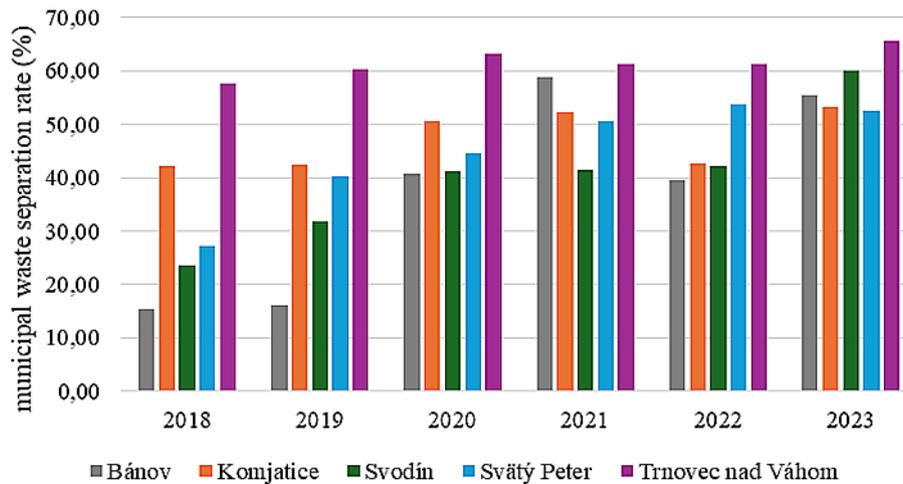
Figure 2. Municipal waste separation rate (%) in the monitored villages

upward trend in separation rates throughout the monitored period. An exception was noted in Komjatice in 2022, where the rate declined from 52.46% in 2021 to 42.69%.

The trends observed in the Slovak Republic are consistent with findings from international studies, which confirm that the volume of municipal waste tends to increase alongside rising living standards. At the same time, waste separation rates have also improved, largely as a result of supportive legislative frameworks in the Slovak Republic [Taušová et al., 2020]. Empirical research conducted in eight Slovak villages further confirmed and theoretically substantiated that the development of both municipal and separated waste follows a linear progressive trend, indicating a sustained increase in both categories [Teplická et al., 2021]. More recent Slovak research published in 2024 demonstrated that the introduction of variable pricing systems – where residents are charged based on the volume of waste generated – significantly increased participation in waste separation. This approach aligns with the European Union's objectives for recycling enhancement and landfill reduction [Tokarčíková et al., 2024].

Comparison of economic performance in waste management

In 2018, the municipality of Bánov reported significantly higher waste management costs (€74.36 per capita) compared to the other monitored municipalities. However, from 2019 to 2023, these values stabilized between €31.07 and €41.62 per capita, which was considered a positive development for the municipality. The lowest per capita costs were recorded in Trnovec nad Váhom: €11.09 in 2020 and €13.39 in 2021, with no data available for 2022.

In Komjatice, a steadily increasing trend was observed over the entire period, from €19.62 per capita in 2018 to €33.97 in 2023, which is assessed as an unfavourable situation. A similar trend of increasing costs was also recorded in Svätý Peter, where costs rose from €16.26 in 2018 to €36.96 per capita in 2023. In Svodín, a declining cost trend was observed only in the final monitored year (2023) compared to the years 2018–2022 (Figure 3).

A comparison of waste management revenues (€ per capita) in the monitored villages are presented in Figure 4. The data show that the villages of Svodín, Svätý Peter, and Trnovec nad Váhom exhibited an increasing trend in revenue development, which was evaluated positively. Furthermore, it was observed that the municipality of Svodín recorded significantly higher revenues in 2021, 2022, and 2023 compared to the other villages of interest.

In terms of the calculated average economic result of waste management (€ per capita), it was found that all villages of interest recorded negative financial outcomes over the six-year period. The worst economic performance in waste management was observed in the municipality of Bánov, with an average result of –€18.68 per capita, while the best result was recorded in Trnovec nad Váhom, with an average of –€5.39 per capita. The villages of Komjatice, Svodín, and Svätý Peter showed comparable results, with averages ranging from –€8.09 to –€7.18 per capita (Figure 5).

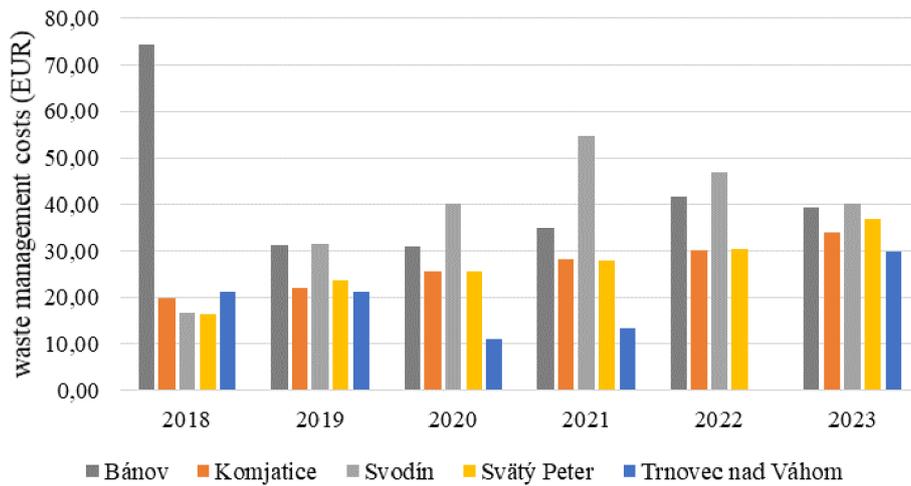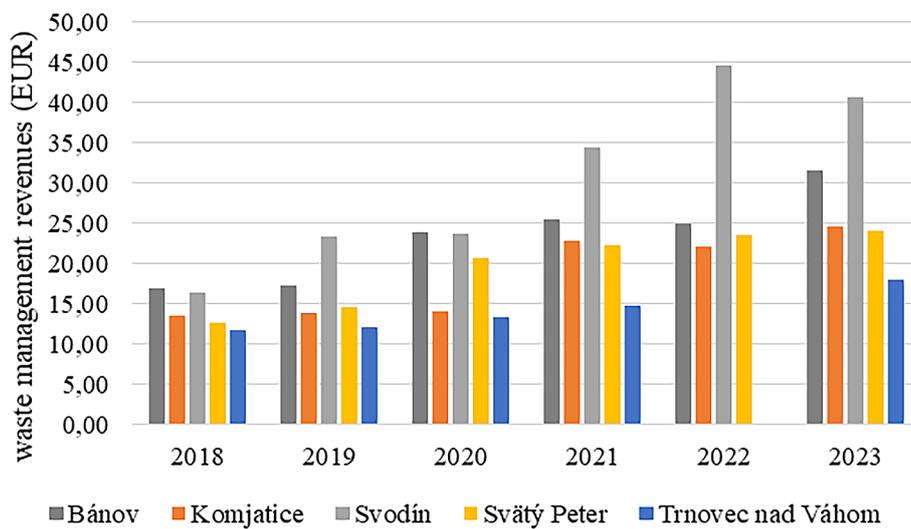**Figure 3.** Waste management costs (€ per capita) in the monitored villages

Figure 4. Waste management revenues (€ per capita) in the monitored villages
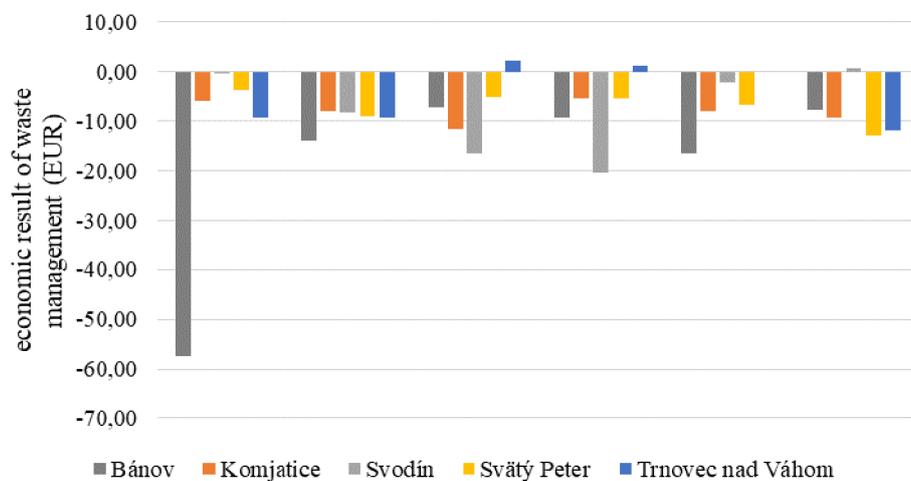

Figure 5. Economic result of waste management (€ per capita) in the monitored villages

Evaluation of results in the monitored municipalities

The municipality of Trnovec nad Váhom achieved the best results in terms of the efficiency and sustainability of municipal waste management, scoring 34 points. It was followed by Svätý Peter with 30 points. Two municipalities, Bánov and Svodín, obtained the same score of 24 points each. The poorest results were recorded in Komjatice, which scored 23 points (Table 2).

On average, villages incurred annual waste management costs of approximately €98,660, corresponding to a mean cost of €31.0 per capita (Table 3). Despite generating average annual revenues of €66,734 (€21.4 per capita), the economic balance remained negative, with an average annual deficit of €31,926 (€9.6 per capita). The average amount of waste generated per municipality was 1,265.9 tonnes, equivalent to 399.3 kg per capita. Notably, the average annual volume of sorted waste (600.6 tonnes) slightly exceeded that of mixed waste (563.5 tonnes). Nevertheless, the overall waste separation rate remained moderate at 46.3%.

These findings indicate progress in waste separation and partial cost recovery; however, further improvements are necessary. Specifically, reducing municipal deficits and enhancing the efficiency of source separation are critical to meeting or surpassing European waste management targets.

The municipality of Bánov had the highest total (€153,978) and per capita (€42.1) waste management costs, while Trnovec nad Váhom recorded the lowest per capita cost (€19.3) and the lowest loss per capita (–€5.4), suggesting greater efficiency. Conversely, Bánov reported the highest deficit (–€68,781; –€18.7 per capita). Fee levels varied from €9.6 (Trnovec nad Váhom) to €27.4 (Svodín), with Svodín also showing strong revenue performance. Mixed waste generation ranged from 362.4 t (Trnovec nad Váhom) to 869.4 t (Komjatice); lower values indicate better sorting. Trnovec nad Váhom led in sorted waste (841.0 t) and sorting rate (61.6%), but also had the highest waste generation per capita (496.9 kg). The lowest sorted volume was observed in Svodín (312.0 t), suggesting lower community participation. The data show systemic budget deficits and moderate sorting rates in all municipalities. However, Trnovec nad Váhom stands out for its cost-efficiency and high separation rate, while Bánov shows the greatest need for improvement.

The correlation matrix provides insight into the relationships among variables in the municipal waste dataset. Total waste production (t) strongly correlates with the number of inhabitants (r = 0.77), confirming that larger villages generate more waste. It is also positively correlated with sorted waste (r = 0.84) and mixed waste (r = 0.59), indicating that both waste fractions contribute to overall waste volume. Waste production per capita shows a significant positive correlation with the waste sorting rate (r = 0.55) and with sorted waste volume (r = 0.80), suggesting that villages with higher per capita waste generation also tend to achieve higher levels of sorting. Sorted waste (t) is strongly correlated with both per capita waste production (r = 0.80) and the sorting rate (r = 0.76), implying that greater waste generation and more efficient sorting practices lead to higher quantities of sorted waste. As expected, the sorting rate negatively correlates with mixed waste (r = –0.36), reflecting that improved separation at source reduces residual waste. It also shows a moderate negative correlation with total waste management costs (r = –0.33), possibly indicating that more efficient systems result in lower overall costs. Waste management costs (€) are strongly correlated with costs

Table 2. Evaluation of overall OH results in the monitored villages for the 6-year period 2018–2023

Municilality	1	2	3				4					Points total
	a	a	a	b	c	Total	a	b	c	d	Total	
Bánov	3	1	1	4	1	6	4	3	4	3	14	24
Komjatice	2	4	4	2	2	8	2	2	3	2	9	23
Svodín	5	2	2	5	3	10	1	1	1	4	7	24
Svätý Peter	4	3	3	3	4	10	5	5	2	1	13	30
Trnovec nad Váhom	1	5	5	1	5	11	3	4	5	5	17	34

Note: 1a – average rate of production of waste in kg per capita, 2a – average rate of sorting of waste in % per capita, 3a – average costs in EUR per capita, 3b – average revenues in EUR per capita, 3c – average operating result in EUR per capita, 4a – average amount of paper and cardboard in kg per capita, 4b – glass in kg per capita, 4c – plastics in kg per capita, 4d – metals/metal packaging in kg per capita)

Table 3. The mean value and standard deviation for each indicator (financial, environmental, demographic) across the five villagesand 6 years

Parameter	Bánov	Komjatice	Svätý Peter	Svodín	Trnovec nad Váhom	Total
Costs of waste management in €	153 978.2 ± 61 654.1	112 702.2 ± 21 503.1	73 343.8 ± 18 159.7	92 738.2 ± 30 853.8	52 912.0 ± 20 768.4	98 659.8 ± 47 628.0
Costs per capita in €	42.1 ± 16.4	26.6 ± 5.3	26.8 ± 6.9	38.4 ± 13.1	19.3 ± 7.4	31.0 ± 13.1
Economic result of the municipal waste management in €	-68 781.2 ± 72 293.6	-34 400.8 ± 9 696.9	-19 656.0 ± 8 952.1	-19 175.7 ± 21 534.6	-14 751.6 ± 18 262.0	-31 925.5 ± 38 819.9
Economic result per capita in €	-18.7 ± 19.4	-8.1 ± 2.3	-7.2 ± 3.3	-7.9 ± 8.9	-5.4 ± 6.7	-9.6 ± 10.7
Fees for waste management in €/capita/year	24.2 ± 6.5	15.8 ± 10.1	21.0 ± 4.6	27.4 ± 8.2	9.6 ± 2.1	19.9 ± 9.0
Mixed waste in t	574.4 ± 78.0	869.4 ± 74.5	563.5 ± 136.1	448.0 ± 132.8	362.4 ± 22.5	563.5 ± 197.1
Number of inhabitants	3 654.0 ± 54.4	4 250.0 ± 43.0	2 744.3 ± 40.4	2 426.8 ± 50.7	2 738.0 ± 38.4	3 162.6 ± 694.2
Revenues from waste management in €	85 197.0 ± 19 080.7	78 301.3 ± 21 293.0	53 687.8 ± 12 751.4	73 562.5 ± 25 434.4	38 160.4 ± 7 361.1	66 734.3 ± 24 336.2
Revenues per capita in €	23.4 ± 5.5	18.5 ± 5.2	19.6 ± 4.9	30.5 ± 11.1	14.0 ± 2.5	21.4 ± 8.3
Sorted waste in t	566.3 ± 349.5	814.7 ± 229.5	469.1 ± 106.2	312.0 ± 107.9	841.0 ± 125.8	600.6 ± 281.6
Waste production in kg/inhabitant	391.2 ± 64.0	400.0 ± 73.6	382.4 ± 32.8	326.1 ± 88.0	496.9 ± 56.8	399.3 ± 82.9
Waste production in t	1 428.0 ± 223.1	1 697.7 ± 299.4	1 049.6 ± 94.4	792.6 ± 218.5	1 361.4 ± 166.2	1 265.9 ± 374.8
Waste sorting rate in %	37.7 ± 18.6	47.3 ± 5.4	44.9 ± 10.0	40.0 ± 12.3	61.6 ± 2.7	46.3 ± 13.5

per capita ($r = 0.87$), revenues from waste management ($r = 0.57$), and negatively with the economic result, both in total ($r = –0.87$) and per capita ($r = –0.84$). These findings suggest that higher waste management costs are a key driver of budget deficits. Revenues from waste management (€) correlate strongly with revenues per capita ($r = 0.78$) and fees per capita ($r = 0.77$), indicating that higher tariffs lead to increased revenue. Fees per capita also correlate with costs per capita ($r = 0.54$), suggesting that villageswith higher service costs often apply higher fees. Economic results and economic results per capita are almost perfectly correlated ($r = 0.98$), as they represent normalized versions of the same variable. Both are strongly negatively correlated with waste management costs ($r ≈ –0.84$ to $–0.87$), confirming that expenditures, rather than revenues, are the principal factor influencing economic performance. Revenues show little to no correlation with environmental performance metrics such as waste production per capita ($r = –0.10$) or the sorting rate ($r = 0.12$). Similarly, fees per capita correlate only weakly with the sorting rate ($r = 0.04$), indicating that higher fees improve revenue generation but have no clear effect on waste separation performance. Overall, villages with higher sorting rates tend to have lower mixed waste volumes and slightly lower waste management costs (see Table 4).

The analysis by the Institute for Environmental Policy (IEP) confirms that local fees usually cover only about 87% of the actual waste management costs, with village shaving to subsidize the rest, which reduces the pressure for efficient sorting and system optimization (IEP, 2023).

Table 5 presents correlation coefficients between the year (typically 2018–2023) and key waste management indicators across five municipalities. These values illustrate temporal trends in waste generation, financial variables, and demographic changes. Total and per capita waste production show strong positive correlations in the villages of Bánov, Komjatice, and Trnovec nad Váhom ($r = 0.50–0.84$), indicating increasing waste generation. This may reflect rising consumption levels or urbanization. In contrast, the number of inhabitants exhibits strong negative correlations in all villages except Trnovec nad Váhom ($r ≤ –0.92$), suggesting ongoing population decline, which may influence waste dynamics differently across regions. The waste sorting rate (%) has increased significantly over time in all villages($r = 0.58–0.93$), indicating successful implementation of policy measures and improved public engagement in waste separation. Similarly, mixed waste volumes have decreased in most villages($r = –0.74$ to $–0.93$), with the exception of Komjatice, where an increasing trend is observed

Table 4. Correlation matrix between studied indicators. Negative correlations are on the blue cells and positive on the red ones. Significant correlations (at α=0.05) are marked with red font

Parameter	Waste t	Inhabitants	Waste kg/capita	Waste sorting rate %	Mixed waste in t	Sorted waste in t	Costs €	Costs/capita	Revenues €	Revenues/capita	Economic result €	Economic result/capita
Inhabitants	0.77											
Waste kg/capita	0.69	0.10										
Waste sorting rate %	0.31	-0.09	0.55									
Mixed waste in t	0.59	0.78	0.05	-0.36								
Sorted waste in t	0.84	0.43	0.80	0.76	0.19							
Costs €	0.26	0.46	-0.13	-0.33	0.30	-0.06						
Costs/capita	-0.13	0.00	-0.23	-0.30	-0.06	-0.29	0.87					
Revenues €	0.26	0.35	-0.10	0.12	0.15	0.21	0.57	0.53				
Revenues/capita	-0.30	-0.28	-0.28	0.14	-0.34	-0.14	0.29	0.57	0.78			
Economic result €	-0.15	-0.34	0.09	0.47	-0.27	0.20	-0.87	-0.74	-0.08	0.12		
Economic result/capita	-0.07	-0.21	0.07	0.47	-0.19	0.25	-0.84	-0.78	-0.05	0.07	0.98	
Fees/capita	-0.24	-0.23	-0.26	0.04	-0.22	-0.16	0.34	0.54	0.77	0.89	0.06	0.02

Table 5. Correlation matrix between years and studied indicators. Negative correlations are on the blue cells and positive on the red ones. Significant correlations (at α=0.05) are marked with red font

Parameter	Bánov	Komjatice	Svodín	Svätý Peter	Trnovec nad Váhom
Waste production in t	0.50	0.83	-0.25	-0.05	0.81
Number of inhabitants	-0.99	-0.97	-0.93	-0.92	0.81
Waste production in kg/inhabitant	0.57	0.84	-0.19	0.11	0.76
Waste sorting rate in %	0.83	0.58	0.93	0.92	0.83
Mixed waste in t	-0.92	0.88	-0.74	-0.93	-0.76
Sorted waste in t	0.74	0.74	0.44	0.90	0.88
Costs of waste management in €	-0.49	1.00	0.69	0.97	0.38
Costs per capita in €	-0.46	1.00	0.72	0.97	0.36
Revenues from waste management in €	0.94	0.91	0.94	0.94	0.98
Revenues per capita in €	0.95	0.91	0.94	0.95	0.98
Economic result of the municipal waste management in €	0.66	-0.21	0.12	-0.62	-0.04
Economic result per capita in €	0.66	-0.25	0.12	-0.64	-0.03
Fees for waste management in €/capita/year	0.91	0.90	0.98	0.83	0.91

(r = 0.88). Conversely, sorted waste has increased consistently across all villages (r = 0.44–0.90), confirming a systemic shift toward more effective sorting practices. Waste management costs, both total and per capita, display divergent trends: strong increases in Komjatice and Svätý Peter (r = 0.97–1.00), and a moderate decline in Bánov (r ≈ –0.50). These differences may reflect varying levels of investment, service expansion, or efficiency gains. Revenues from waste management (total and per capita) have increased steadily across all villages (r = 0.91–0.98), likely due to improved fee collection, price adjustments, or enhanced material recovery. Fees per capita also show strong upward trends (r = 0.83–0.98), supporting the interpretation that villages are adopting more cost-reflective pricing strategies. Economic results vary: Bánov shows improvement over time (r = 0.66), while Svätý Peter exhibits a declining trend (r = –0.62). In Komjatice and Trnovec nad Váhom, no clear trend is observed, suggesting fiscal stability or fluctuating economic performance.

In summary, most villages demonstrate progress in waste sorting and revenue generation.

However, demographic decline – except in Trnovec nad Váhom – may present challenges for future waste management planning. Financial sustainability remains uneven, with some villages improving their balances while others face persistent deficits.

There is strong multicollinearity among several economic variables (costs, revenues, fees, and results). In the PCA model, was retained one of each pair. Principal component analysis (PCA) was employed to visualize the relationships between villages and key variables in a reduced-dimensional space. This method simplifies complex multivariate data by identifying principal components (PCs) that capture the majority of variance. The first two components, PC1 and PC2, account for 79% and 17% of the total variance, respectively. Villages are projected as squares based on their multivariate profiles. Bánov and Svodín are positioned in association with higher costs, fees, and mixed waste shares, reflecting less favourable waste structures. In contrast, Trnovec nad Váhom aligns with higher waste sorting rates and lower financial expenditures, indicating a more sustainable and efficient system. Komjatice and Svätý Peter occupy intermediate positions, suggesting balanced performance and possibly transitional profiles across the evaluated indicators. In terms of variable loadings, costs, fees, and revenues per capita are strongly positively correlated and point in the same direction. Mixed waste percentage aligns with these financial variables, indicating that higher expenditures are associated with greater proportions of unsorted waste. Conversely, the waste sorting rate and waste generation per capita point in the opposite direction, suggesting a negative correlation with financial input and residual waste.

The economic result per capita is oriented downward in the plot, indicating a distinct pattern from other economic variables such as costs and revenues. This separation highlights that better economic outcomes are not necessarily driven by higher spending but may relate to system efficiency.

CONCLUSIONS

The evaluation of municipal waste management in five Slovak villages from 2018 to 2023 reveals significant differences in efficiency, financial performance, and environmental outcomes.

Trnovec nad Váhom consistently achieved the best results, combining high separation rates, low costs, and relatively strong economic performance. Bánov, on the other hand, recorded the highest per capita costs and largest deficits, indicating inefficiencies despite some recent improvements. Overall, all villages operated with negative economic results, mainly due to rising costs rather than insufficient revenues. Waste separation improved over time across most municipalities, supported by legislative frameworks and increasing public participation. Nonetheless, the average sorting rate remained moderate, highlighting room for progress. Statistical correlations confirmed that higher waste generation per capita is linked with improved sorting rates and higher volumes of separated waste. PCA findings further underscored the contrasting profiles of municipalities, from cost-efficient to high-expenditure systems. Despite systemic challenges such as demographic decline and budgetary imbalance, positive trends in sorting and revenue generation indicate gradual progress. To achieve long-term sustainability and align with EU targets, villages must reduce mixed waste, optimize costs, and improve the economic balance of waste management systems. This study contributes by providing a practical assessment of waste management in smaller municipalities, offering valuable insights for local governments and regional authorities to support informed decision-making. Moreover, it highlights the importance of increasing environmental awareness among residents and ensuring the sustainable financing of waste management systems.

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