



Evaluation and comparison of results of the 2022-2023 national EPR based MSW analytical campaigns.

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Abstract

The study is Evaluation and Comparison of 2022-2023 National EPR-Based MSW Analytical Campaigns in Hungary

In response to the escalating environmental challenges posed by municipal solid waste (MSW), Hungary has implemented the Extended Producer Responsibility (EPR) systems and introduced the Deposit Refund Systems (DRS) for certain consumer packaging's. This study aims to evaluate and compare the outcomes of the national EPR-based MSW analytical campaigns conducted in the autumn and winter of 2022 and the spring and summer of 2023. Emphasizing the significance of selective waste collection and recycling, this research scrutinizes the effectiveness of these initiatives in managing MSW, particularly in the context of Hungary's commitment to sustainable waste management.

Methodologically, this research undertakes a comprehensive literature survey on European EPR and DRS systems, specifically focusing on their national applications in Hungary. It adheres to the Hungarian EPR MSW analytical standards (MSZ 21420-28 and 29) and involves the development of a novel computer solution for parsing and evaluating compositional data from existing databases. This study employs a multi-faceted approach to data analysis, selecting key parameters to represent the composition of various waste streams and establishing criteria for comparison, such as key component concentration, seasonal changes, regional disparities (NUTS2 regions) and waste stream types.

Preliminary findings reveal significant variances in waste composition and management efficacy across different regions and seasons. The study several and highlights the varying degrees of success in implementing EPR and DRS across Hungary, with some regions showing marked improvements in waste segregation and recycling while others lag behind. Notably, the research underscores the critical role of public awareness, policy enforcement, and infrastructure adequacy in the success of EPR and DRS initiatives.

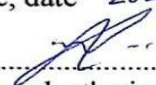
The results of this research contributes to a nuanced understanding of waste management in Hungary, offering valuable insights into the strengths and areas for improvement within the EPR and DRS frameworks. The findings hold implications for policy refinement, suggesting targeted

strategies for enhancing waste management efficiency, promoting environmental sustainability, and facilitating Hungary's transition to the circular economy. Conclusively, this study serves as a cornerstone for future research and policy development in sustainable waste management within Hungary and a broader European context.

Declaration of authenticity

The undersigned Aladdin Almarashly, a student of the University of Miskolc, aware of my criminal and disciplinary liability, I declare and confirm with my signature that I have prepared this thesis myself, that I have carried out the tests described in it – if not indicated separately – myself, and that I understand the presented results myself away. I used data and information only from the sources listed in the bibliography. All parts that I have taken verbatim or paraphrased from another source have been clearly marked with the source.

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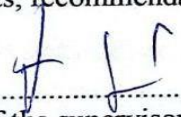

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Declaration of the supervisor

I, the undersigned Prof. Dr. József Faitli, University of Miskolc, Institute of Raw Materials Preparation and Environmental Technology consider the TDK thesis suitable for submission.

Other comments, recommendation:

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1. Introduction

The management of municipal solid waste (MSW) is a critical challenge modern societies face, particularly in the context of increasing urbanization, consumerism, and environmental concerns. In Hungary, like in many other European countries, the generation of significant quantities of MSW poses both logistical and environmental challenges. The effective management of this waste is not only essential for maintaining public health and hygiene but also for the protection of the environment and the promotion of sustainable development.

The traditional approach to MSW management, often centered around landfilling and incineration, is increasingly being replaced by more sustainable methods. These methods emphasize waste reduction, reuse, recycling and recovery. In this regard, the European Union has been a frontrunner, implementing various directives and policies to improve waste management practices among its member states.

1.1. Extended Producer Responsibility (EPR) and Deposit Refund Systems (DRS)

Extended Producer Responsibility (EPR) is a policy approach where producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. The aim is to encourage producers to consider the end-of-life impact of their products and thus design more environmentally friendly ones.

Deposit Refund Systems (DRS) are specific types of EPR, where consumers pay a small deposit on a product, which is refunded when they return the product or its container for recycling. DRS has been particularly effective in increasing beverage container collection and recycling rates.

In Hungary, the adoption of EPR and DRS for some plastics, metals, and glass consumer packaging is a significant step towards a more sustainable approach to waste management. This shift aligns with the broader European trend towards a circular economy, where the value of products and materials is maintained for as long as possible, and the generation of waste minimized.

1.2. Objective of the Study

The primary objective of this study is to evaluate and compare the results of the national EPR-based MSW analytical campaigns conducted in Hungary during the autumn and winter of 2022,

and the spring and summer of 2023 by University of Miskolc. This analysis is crucial for assessing the effectiveness of Hungary's EPR and DRS policies in managing MSW.

The methodology for this study is rooted in the standards set by the existing MSZ 21420-28 and 29 MSW sampling standards. These standards were accepted based on the research carried out by the institute, and provide a comprehensive framework for sampling, analyzing, and interpreting MSW data. The study's approach involves a detailed survey of the literature on European EPR and DRS MSW systems, and their national applications in Hungary, as well as a critical analysis of the Hungarian EPR MSW analytical methodology.

A key aspect of this TDK study is the development of a computer solution for the evaluation of compositional data from the existing database. This technological approach allows for a more efficient and accurate analysis of large data sets, facilitating a more comprehensive understanding of MSW composition and management in Hungary.

This TDK study is significant for several reasons. Firstly, it contributes to the body of knowledge on waste management in Hungary, providing insights into the effectiveness of EPR and DRS systems in a national context. Secondly, it offers a critical evaluation of Hungary's approach to MSW management, identifying strengths and areas for improvement. Finally, the findings of this study have the potential to inform policy decisions and operational practices in waste management, not only in Hungary but also in other countries considering or implementing similar EPR and DRS systems.

In the following sections, the TDK study will delve deeper into the literature review, methodology, analysis, and findings, culminating in a set of recommendations for enhancing MSW management in Hungary.

2. Literature Review

2.1. European EPR and DRS MSW Systems

The European approach to Municipal Solid Waste (MSW) management has significantly evolved with the adoption of Extended Producer Responsibility (EPR) and Deposit Refund Systems (DRS). These systems are integral to Europe's strategy to address the environmental challenges posed by MSW. This section reviews the implementation of EPR and DRS across Europe, focusing on their impact and effectiveness in MSW management.

EPR in Europe places the responsibility of post-consumer product treatment or disposal on producers, encouraging them to design environmentally friendly products. The success of EPR in Europe, as noted in studies like that by Maris et al. (2015), lies in its ability to enhance recycling rates and reduce waste in landfills. Each European country has tailored EPR systems to fit its specific waste management needs and policies. For instance, as detailed in the research by Laubertova et al. (2018), countries have adopted EPR for various waste streams, including packaging waste, electrical and electronic equipment, and end-of-life vehicles.

DRS, a specialized form of EPR, has been particularly effective in European countries for the managing beverage container waste. Consumers paying a deposit at the time of purchase, refunded upon the return of the container, it has significantly improved recycling rates. The effectiveness of DRS in reducing litter and promoting recycling is well-documented in studies like those by Rodríguez et al. (2017), highlighting the system's simplicity and the direct financial incentive for consumers.

Comparative studies across Europe reveal that the success of EPR and DRS hinges on factors like transparency, stakeholder involvement, and clear targets. As explored in the work by Vojtonovszki-Soltész and Faitli (2019), these factors vary significantly across European nations, influencing the effectiveness of each country's EPR and DRS systems.

The implementation of EPR and DRS in Europe aligns with the European Union's broader policies on waste management, including the Waste Framework Directive and the Circular Economy Package. These systems contribute to reducing litter, conserving resources, and lowering greenhouse gas emissions, as noted in the EN 14243 standards. The environmental and economic

benefits of these systems are evident across Europe, fostering a transition to a more sustainable and circular economy.

EPR and DRS systems have become key elements in Europe's strategy to manage MSW effectively. The varied implementation of these systems across Europe offers valuable lessons and insights for other regions, including Hungary. As Europe continues to refine its waste management strategies, the experiences gained from EPR and DRS implementations will remain crucial in shaping future sustainable waste management practices.

2.2. National Applications in Hungary

The transformation in waste management strategies in Hungary, especially with the adoption of Extended Producer Responsibility (EPR) and Deposit Refund Systems (DRS), reflects the country's alignment with European Union directives and its commitment to the circular economy. This section reviews the national application of these systems in Hungary, focusing on their implementation and impact on Municipal Solid Waste (MSW) management.

Hungary has integrated EPR into its waste management framework, emphasizing producer responsibility for various types of waste, including packaging, electrical and electronic equipment, and end-of-life vehicles. The evolution of Hungary's EPR approach is detailed in the works of Faitli et al. (2023a), highlighting the initial challenges and the progressive improvements made to establish more effective waste management systems. This progression demonstrates Hungary's efforts to adapt and refine its EPR strategies to meet specific national requirements.

The deployment of DRS, particularly for packaging waste in Hungary, marks a significant advancement in the country's waste management strategy. Faitli et al. (2023b) examine the impact of DRS on the collection and recycling rates of packaging materials. The studies underline the importance of consumer incentives and the effectiveness of DRS in reducing litter and promoting recycling practices.

Despite advancements, challenges persist in the full realization of EPR and DRS systems in Hungary. Issues such as the adaptation of these systems to local contexts and the need for robust infrastructure are discussed in various studies, including those by Vojtonovszki-Soltész and Faitli (2019). These challenges underscore the need for continuous policy refinement and infrastructure development to enhance the effectiveness of EPR and DRS in Hungary.

The environmental and economic implications of implementing EPR and DRS in Hungary are significant. Reductions in landfill waste, resource recovery improvements, and economic benefits from the recycling industry are among the positive outcomes reported in studies like that of Rodríguez et al. (2017). These impacts highlight the potential of EPR and DRS systems to contribute to sustainable waste management and economic development.

The national application of EPR and DRS in Hungary represents an important step toward modernizing waste management practices in line with European standards. While there are ongoing challenges, the positive outcomes observed provide a foundation for future enhancements. As Hungary continues to refine its waste management strategies, lessons learned from EPR and DRS implementations offer valuable insights for further improvements.

2.3. Hungarian EPR MSW Analytical Methodology

The Extended Producer Responsibility (EPR) Municipal Solid Waste (MSW) analytical methodology in Hungary has been developed based on the MSZ 21420-28 and 29 MSW (2005) sampling standards. This methodology is integral to Hungary's strategy for effective waste management under the EPR framework, providing a systematic approach for the sampling, analysis, and interpretation of MSW data.

The Methodological Framework is:

- **Adherence to MSZ Standards:** The methodology strictly adheres to the guidelines set forth in the MSZ 21420-28 and 29 MSW (2005) sampling standards, ensuring consistency and reliability in the data collection process.
- **Sampling Techniques:** Sampling involves strategically selecting locations across various NUTS2 regions, considering factors like population density and urbanization. This approach ensures that the samples are representative of the waste generated in different areas.
- **Analytical Procedures:** The methodology incorporates both quantitative and qualitative analyses. Quantitative analysis includes measuring the volume and weight of waste samples, while qualitative analysis focuses on identifying the composition and characteristics of the waste.

The implementation of this methodology in Hungary faces several challenges:

- **Ensuring Data Consistency:** Maintaining data consistency across different regions and over time is crucial. The standardized procedures outlined in the MSZ standards help mitigate inconsistencies in data collection and analysis.

- **Local Adaptation:** The methodology is adapted to the local contexts of various Hungarian regions, ensuring its applicability in diverse urban and rural settings. This adaptation is crucial for capturing an accurate picture of waste management practices across the country.

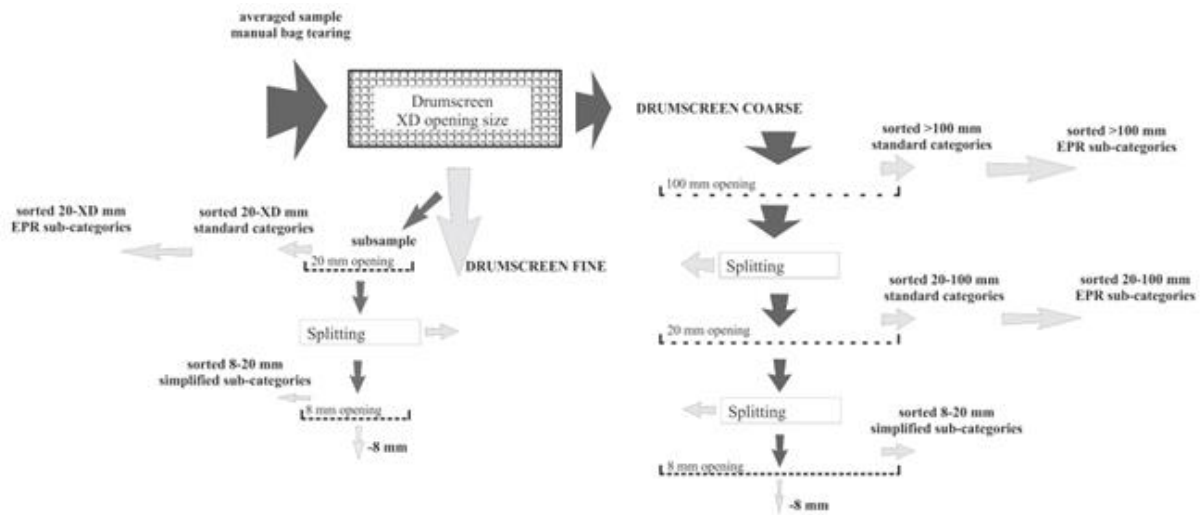


Figure 1 The general flow sheet of the averaged sample processing with a drum screen. Faitli et al. (2023b)

2.4. Computer Programming, Dissemination, and Evaluation Methodologies

The use of computer programming in municipal solid waste (MSW) management has become increasingly vital, especially under the Extended Producer Responsibility (EPR) framework. Advanced software tools are essential for processing and analyzing the complex data sets generated from EPR-based MSW analytical campaigns. According to Faitli et al. (2023a), specialized software solutions facilitate efficient handling of waste composition data, enhancing the accuracy and depth of analysis. This computerized approach allows a more comprehensive understanding of waste characteristics and gives valuable feed back for waste management strategies.

Effective dissemination of EPR and DRS-related MSW data is crucial to inform stakeholders and guide policy decision makers. Digital platforms play a pivotal role in disseminating MSW data, providing accessible and engaging ways to present complex information to diverse audiences. Utilizing online resources and social media channels ensures broad reach and facilitates the engagement of various stakeholders in the waste management process.

The evaluation of MSW management practices involves analyzing data collected from various sources, including waste sampling and sorting protocols. For instance, Faitli and Romenda (2019) detail a comprehensive sampling protocol for analyzing residual municipal solid wastes, contributing to the robustness of the evaluation process. This protocol forms an integral part of the EPR MSW analytical methodology, ensuring the accuracy and reliability of data used in assessing waste management practices.

The EPR MSW methodology integrates advanced analytical techniques to assess the composition and properties of waste materials. Studies like those by Depaolini et al. (2017) and Maris et al. (2015) provide insights into the physical and chemical characterization of specific waste streams, such as recycled rubber and plastics from WEEE (Waste Electrical and Electronic Equipment). Such detailed analyses are essential for tailoring waste management strategies under the EPR framework.

The use of computer programming, coupled with effective dissemination and advanced evaluation methodologies, significantly enhances the management of MSW under the EPR framework. These methodologies provide the tools necessary for comprehensive waste analysis, allowing for informed decision-making and policy development in waste management.

2.5. Statistical Evaluation of Sampling Data

Statistical evaluation plays a crucial role in the analysis of Municipal Solid Waste (MSW) sampling data, especially in the context of Extended Producer Responsibility (EPR) and Deposit Refund Systems (DRS). This section delves into the methodologies and significance of statistical evaluations in managing MSW effectively.

The process of statistically evaluating MSW sampling data involves several key methodologies. Primarily, this includes the application of descriptive statistics to summarize and describe the features of a dataset. This approach, as detailed in the studies by Maris et al. (2015), involves calculating means, medians, modes, and standard deviations to understand the central tendencies and dispersion of waste data. Additionally, inferential statistics are used to make predictions or inferences about a population based on a sample of data. This is particularly relevant

in studies like those conducted by Laubertova et al. (2018), where sampling data from specific regions or periods are used to make broader generalizations about waste trends.

Advanced statistical techniques such as regression analysis, time-series analysis, and multivariate analysis play a significant role in evaluating MSW data. For instance, regression analysis can be used to understand the relationship between various factors influencing waste generation, as explored in the research by Rodríguez et al. (2017). Time-series analysis is beneficial for identifying trends over time and is particularly useful in assessing the impact of policy changes or seasonal variations on waste generation and management.

The statistical evaluation of MSW data often is accompanied by challenges. One of the primary challenges, as indicated in the work by Vojtonovszki-Soltész and Fajtli (2019), is treating the heterogeneity and complexity of waste data. The varied nature of waste components, differing collection and management practices across regions, and the dynamic nature of waste generation all contribute to the complexity of the data. Additionally, ensuring the accuracy and reliability of sampling methods is crucial for valid statistical analysis.

Statistical evaluation of MSW data is integral to informed policy-making in waste management. By providing a robust analysis of waste composition, generation rates, and management efficiency, statistical evaluations guide policymakers in designing and implementing effective EPR and DRS strategies. The insights gained from these analyses, as highlighted in the EN 14243 standards, are crucial for developing targeted waste reduction, recycling, and management initiatives.

Statistical evaluation is an essential component of MSW management, particularly in the context of EPR and DRS systems. Advanced statistical methodologies provide the tools necessary to analyze complex waste data, enabling stakeholders to make informed decisions and implement effective waste management strategies. As MSW management practices continue to evolve, the role of statistical evaluation in shaping sustainable and effective waste management policies becomes increasingly significant.

3. Methodology

3.1. Selection of Key Parameters

The selection of key parameters for the analysis of Municipal Solid Waste (MSW) under the Extended Producer Responsibility (EPR) and the upcoming Deposit Return System (DRS) is crucial in understanding the composition and dynamics of waste streams. This section discusses the methodology adopted for processing an averaged sample, focusing on standard material categories and EPR and future DRS sub-categories. The EPR methodology is based on the MSZ 21420-28 and 29 MSW (2005) sampling standards, but it has been extensively improved as described in the "Methodology Instructions" Faitli et al. (2023a)

The study focuses on a broad range of waste streams categorized under DRS-W, EPR-P, Plastic, Bio, and Food. Each category comprises various sub-categories, reflecting the diverse nature of waste materials. For instance, under DRS-W, specific attention is given to different types of beverage bottles (plastic, glass, Fe metal, Al metal) and their future subject to DRS. Similarly, the EPR-P category includes various packaging materials such as paper, cardboard, composite packaging, and textiles.

The methodology involves processing averaged samples collected from waste-collecting vehicles, representing the raw sample. This approach ensures a representative analysis of the waste composition in different regions and seasons. The key parameters are selected based on their relevance to the study's objectives, which include understanding the composition of waste streams, assessing the impact of EPR and DRS policies, and identifying opportunities for recycling and waste reduction.

The sub-categorization of materials under the main waste streams, as utilized during the national MSW campaigns in 2022 and 2023 by the University of Miskolc, Institute of Raw Materials Preparation and Environmental Technology, is employed in this analysis. This EPR (Extended Producer Responsibility) MSW material subcategorization has been specifically chosen for its relevance and applicability. For the purpose of this study, I have selected five key parameters. The EPR-based subcategorization of these parameters is as follows:

1. DRS-W - Deposit Return System

- a. 7.3 -Plastic DRS beverage bottle (PET or other plastic bottles, soft drink, mineral water, and beer bottles in the future subject to DRS, except bottles of milk and drinkable dairy products)
 - b. 9.1 - DRS glass (in the future DRS glass beverage bottles)
 - c. 10.1 - DRS metal Fe (in the future, Fe beverage cans, soft drink, mineral water, and beer iron metal beverage cans subject to DRS, excluding milk and drinkable milk products)
 - d. 10.2 - DRS metal Al (in the future, Al beverage cans under DRS (soft drink, mineral water, beer aluminum beverage cans, excluding milk and drinkable milk products)
2. EPR-P - Extended Producer Responsibility
- a. 2.1 - Packaging paper (paper packaging)
 - b. 3.1 - Packaging cardboard (packaging cardboard, pasta, and egg boxes, yogurt cartons, corrugated packaging cartons, etc.)
 - c. 4.1 - 3D composite packaging (associated layered beverage cartons, e.g., TetraBrik, milk, and fruit juice composite packaging)
 - d. 4.2 - 2D composite packaging (other foil-like multilayer packaging materials, e.g., nuts, chips, etc.)
 - e. 5.1 - Textile packaging material (nets for fruits and vegetables, etc.)
 - f. 7.1. - 2D packaging (plastic advertising bag, 2D plastic packaging materials, films, biodegradable 2D packaging made of PLA)
 - g. 7.3 - Plastic DRS beverage bottle (PET or other plastic bottles, soft drink, mineral water, and beer bottles in the future subject to DRS, except bottles of milk and drinkable dairy products)
 - h. 7.4 - Plastic non-DRS beverage bottle (PET or other plastic bottles of milk and drinkable dairy products)
 - i. 7.5. - 3D packaging plastic (HD-PE and other plastic bottles, detergent and other bottles, glasses, plates, food containers, etc.)
 - j. 8.1 - Wooden packaging (wooden and natural-based packaging materials, cork stoppers, wooden caps)
 - k. 9.1 - DRS glass (in the future DRS glass beverage bottles)
 - l. 9.2 - Packaging glass (other glass packaging materials, e.g., preserves, jam, milk, drinkable milk products, etc.)
 - m. 10.1 - DRS metal Fe (in the future, Fe beverage cans, soft drink, mineral water, and beer iron metal beverage cans subject to DRS, excluding milk and drinkable milk products)
 - n. 10.2 - DRS metal Al (in the future, Al beverage cans under DRS (soft drink, mineral water, beer aluminum beverage cans, excluding milk and drinkable milk products)
 - o. 10.3 - Fe packaging and spray (other Fe packaging materials and Fe spray bottles, glass packaging Fe cap separately, Fe spray, etc.)

- p. 10.4 - Al packaging and spray (other Al packaging materials and Al spray bottles, e.g., aluminum foil, yogurt cap separately, glass packaging Al cap separately, Al spray, etc.)
 - q. 12.2 - Hazardous packaging (packaging contaminated with pesticides, paints, varnishes or solvents, pharmaceutical packaging with or without drug residue (without the outer paper box), etc.)
3. Plastics
- a. 7.1 - 2D packaging (plastic advertising bag, 2D plastic packaging materials, films, biodegradable 2D packaging made of PLA)
 - b. 7.2 - 2D non-packaging (2D-shaped plastic foils, e.g., for agricultural purposes – ground cover foils, tent foils, balloons, etc.)
 - c. 7.3 - Plastic DRS beverage bottle (PET or other plastic bottles, soft drink, mineral water, and beer bottles in the future subject to DRS, except bottles of milk and drinkable dairy products)
 - d. 7.4 - Plastic non-DRS beverage bottle (PET or other plastic bottles of milk and drinkable dairy products)
 - e. 7.5 - 3D packaging plastic (HD-PE and other plastic bottles, detergent and other bottles, glasses, plates, food containers, etc.)
 - f. 7.6 - 3D non-packaging plastic (non-packaging 3D-sized plastic particles, e.g., toys, tools, ear picks, balloon sticks, plastic-straw-mixing sticks, etc.)
 - g. 13.1 - 8-20 mm PLASTIC
4. Bio - BIOLOGICALLY DECOMPOSABLE WASTE
- e. 1.1 - Food waste (without bones)
 - f. 1.2 - Green waste (yard and garden green wastes, flowers, leaves, hedge cuttings, etc.)
 - g. 1.3 – fat - Cooking oil and fat (bottles containing cooking oil and fat, in which the weight of the content is greater than the packaging)
 - h. 13.5 - 8-20 mm BIO
5. Food
- i. 1.1 - Food waste (without bones)

Each sub-category is defined based on its material composition and potential for recycling or recovery, reflecting the comprehensive approach of the EPR system in waste management.

The sampling procedure involves collecting waste from waste-collecting vehicles, ensuring a comprehensive representation of MSW. The analytical process then categorizes the waste into predefined sub-categories, followed by quantitative and qualitative assessments. This approach allows for detailed analysis of the composition, weight, and potential recyclability of each waste type.

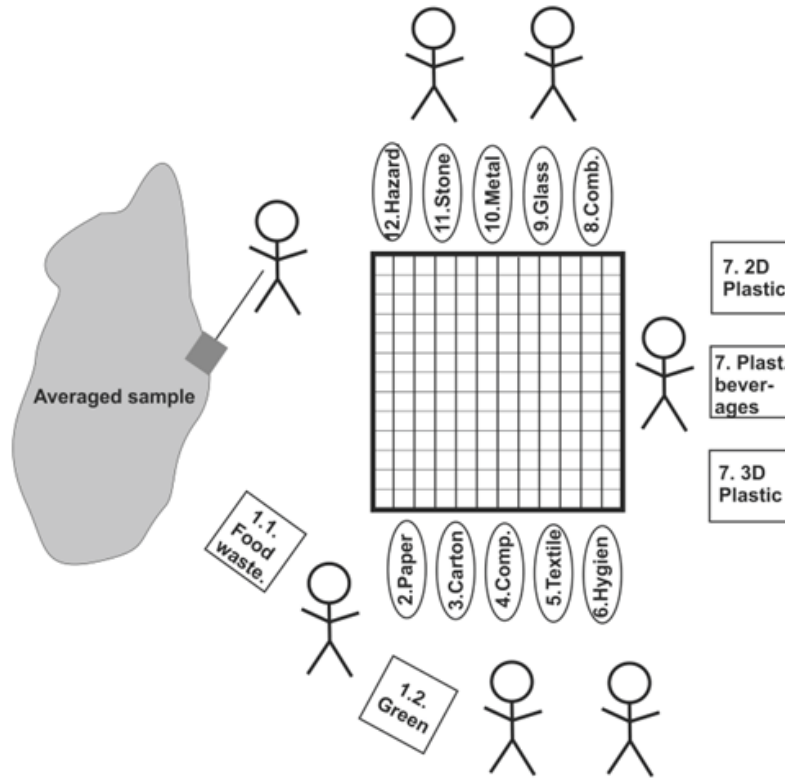


Figure 2 Expedient arrangement of primary (standard) sorting, Faitli et al. (2023b)

One of the challenges in this methodology is ensuring the accurate categorization and assessment of diverse and complex waste streams. Additionally, adapting the methodology to local contexts and waste management practices is crucial for reliable and relevant results.

The selection of key parameters for MSW analysis under the EPR and DRS frameworks is a critical step in understanding waste composition and dynamics. This methodology provides a structured approach to categorize and analyze various waste streams, contributing to more informed waste management strategies and policy development.

3.2. Data Collection

The data collection process for evaluating Municipal Solid Waste (MSW) management in Hungary, particularly under the Extended Producer Responsibility (EPR) framework, is a crucial component of the research methodology. This section outlines the data collection approach, referencing the protocols and data provided by the University of Miskolc. The data encompasses various aspects of waste management, spanning different seasons and categories for the years 2022 and 2023.

The data covers two distinct years, 2022 and 2023, and is segmented into four seasonal periods:

- Autumn 2022
- Winter 2022
- Spring 2023
- Summer 2023

This temporal division allows for an analysis of seasonal variations in waste generation and management, providing insights into how different times of the year impact waste composition and volume.

For each season, the data is further categorized into four main types, reflecting different aspects of waste management:

1. **Illegally Deposited Waste:** This category includes waste that has been disposed of illegally, such as littering or unauthorized dumping. Analyzing this data helps in understanding the extent and nature of non-compliant waste disposal practices.
2. **Public Cleaning Waste:** This encompasses waste collected through public cleaning efforts, providing insight into the volume and type of waste generated in public spaces.
3. **Selective Municipal Solid Waste (SMSW):** This category refers to waste that has been segregated at the source for recycling or special disposal, such as paper, plastics, or organic waste.
4. **Mixed Municipal Solid Waste (MSW):** This includes general household waste and other waste types that have not been segregated, offering a broad view of the overall waste composition.

The data collection process involves gathering information from various sources, including municipal waste collection services, public cleaning records, and monitoring systems for illegal dumping. The methodology adheres to the standards set by MSZ 21420-28 and 29 MSW sampling standards, ensuring consistency and reliability in the data.

- **Sampling and Sorting:** Waste is sampled and sorted based on predefined categories to accurately assess its composition. This involves physical sorting of waste and categorization according to material type, source, and disposal method.
- **Quantitative Measurement:** The collected waste is quantitatively measured to determine its volume and weight, providing essential data for statistical analysis.
- **Quality Control:** Regular checks and quality control measures are in place to ensure the accuracy and consistency of the data collected.

Data collection for MSW management is complex and faces several challenges. Ensuring representative sampling across different regions and seasons, managing the logistics of waste collection and sorting, and maintaining data accuracy are some of the critical challenges in this process.

The data collection methodology for MSW management under the EPR framework in Hungary is comprehensive and well-structured, covering a wide range of waste types and management practices. The seasonal and categorical division of the data provides a nuanced understanding of waste management dynamics, which is crucial for effective policy development and waste management strategies. This robust data collection approach, facilitated by the University of Miskolc, forms the foundation for a detailed and accurate analysis of waste management practices in Hungary.

3.3. Development of Computer Solution

The development of a computer solution for analyzing Municipal Solid Waste (MSW) data is a pivotal aspect of modern waste management research. In this research, data provided by the University of Miskolc, initially in Excel format, has been processed and converted into a MongoDB database using Python. This section discusses the methodology employed in developing this computer solution, highlighting the steps from data acquisition to database implementation and its readiness for analysis.

The initial dataset, provided in a total of 16 Excel files by the Institute, encompasses comprehensive details about various waste streams and categories for the years 2022 and 2023. Excel, being a widely used tool for data storage and preliminary analysis, offers a familiar and accessible format for collecting and distributing data. However, for more advanced analysis, especially involving large datasets as presented in these 16 files, Excel may have limitations in terms of data processing capabilities and scalability. The volume of data and the need for complex analyses can challenge Excel's capacity, necessitating the use of more robust data management and analysis tools.

To address these limitations and facilitate more sophisticated analyses, the data was read and processed using Python, a versatile programming language well-suited for data analysis. Python's ability to handle various data formats and its compatibility with numerous data processing libraries makes it an ideal choice for this task.

- **Reading Data with Python:** The data from the Excel files was read using Python, utilizing the 'openpyxl' library. This step involved cleaning, normalizing, and structuring the data to ensure its integrity and usability. 'openpyxl' is particularly adept at handling Excel files, allowing for efficient access and manipulation of data within these files. This process is crucial for preparing the data for subsequent analysis and ensuring that it is accurately represented in the database.
- **Conversion to MongoDB:** The processed data was then converted into a MongoDB database. MongoDB, a NoSQL database, is chosen for its scalability, flexibility in handling unstructured data, and efficient querying capabilities. This database structure is particularly beneficial for handling large datasets with varied data types and structures, as is common in MSW management.
- **Data Structuring:** In MongoDB, data is stored in JSON-like documents, allowing for a more dynamic schema. This is particularly useful for MSW data, which can vary significantly in structure and content. The conversion process included structuring the data into an appropriate format that facilitates easy retrieval and analysis.

The Advantages of the Developed Computer Solution:

- **Enhanced Data Management:** MongoDB offers superior data management capabilities, especially for large and complex datasets, compared to traditional spreadsheet tools.
- **Scalability and Flexibility:** The NoSQL nature of MongoDB allows for greater scalability and flexibility in data handling, accommodating future expansions or modifications in the dataset.
- **Advanced Analysis Capabilities:** With the data now in MongoDB, advanced analytical operations can be performed more efficiently. Python, in conjunction with MongoDB, enables the application of complex analytical algorithms, statistical models, and machine-learning techniques.

The development of a computer solution comprising Python for data processing and MongoDB for data storage marks a significant advancement in the analysis of MSW data. This solution not only enhances the efficiency and effectiveness of data analysis but also provides a robust platform for future research and exploration in waste management. This innovative approach aligns with modern data processing trends and sets a strong foundation for comprehensive waste management analysis.

4. Comparative Analysis

4.1. Comparison Criteria

In conducting a comparative analysis of Municipal Solid Waste (MSW) management across different NUTS2 regions in Hungary, it is crucial to consider regional variations, particularly in

population. This section outlines the comparison criteria used in the study, emphasizing the importance of weighting regions based on population to ensure an accurate and fair analysis.



Figure 3 NUTS2 Regions of Hungary

The population of each NUTS2 region in Hungary significantly influences the generation and management of MSW. To account for these differences, a mathematical weighting system based on population is employed. This approach ensures that the analysis accurately reflects the waste management situation relative to the population size in each region. The following weights are assigned to each region based on its population:

	Population	Weight
Budapest	1,706,851	0.176
Pest County	1,325,036	0.137
Central Transdanubia	1,056,295	0.109
Western Transdanubia	997,119	0.103
South Transdanubia	864,299	0.089
Northern Hungary	1,102,064	0.114
Northern Great Plain	1,423,751	0.147

Southern Great Plain	1,213,595	0.125
Hungary	8,692,888	1.000

Table 1 NUTS2 region weights

These weights are calculated as the proportion of each region's population relative to the total population of Hungary.

4.1.1. Weighted Mean Calculation

The Weighted Mean is used to calculate the average value for a particular waste metric (such as volume or composition) across the regions, taking into account the population weight of each region. The formula for the Weighted Mean ($\bar{X}_w$) is as follows:

$$\bar{X}_w = \left(\sum_{i=1}^n (X_i \times W_i) \right) / \left(\sum_{i=1}^n W_i \right) \quad (1)$$

Where:

- X_i = Value of the metric (e.g., Mass of waste) in region i
- W_i = Mathematical Weight (population proportion) of region i
- n = Number of regions

For our case, the total number of sum weights is 1 for that:

$$\bar{X}_w = \sum_{i=1}^n (X_i \times W_i) / 1 \quad (2)$$

4.1.2. Corrected Sample Standard Deviation

To evaluate the variability of waste data across different regions, the Corrected Sample Standard Deviation is calculated. This statistical measure provides insights into the dispersion or spread of data around the weighted mean. The formula for Corrected Sample Standard Deviation (S_u^*) is:

$$S_u^* = \sqrt{\frac{n}{1-n} * \sum_{i=1}^n W_i (X_i - \bar{X}_w)^2} \quad (3)$$

This formula takes into account the weights of each region, providing a more accurate measure of variability in weighted data sets.

4.1.3. Application in Comparative Analysis

Using these criteria, the comparative analysis will assess various aspects of MSW management, such as waste generation, segregation efficiency, and recycling rates across the different NUTS2 regions. The Weighted Mean and Corrected Standard Deviation will be instrumental in understanding regional differences and identifying areas that require policy intervention or enhanced waste management practices.

The comparative analysis, grounded in a statistically rigorous approach, is essential for a comprehensive understanding of MSW management across Hungary's diverse regions. By incorporating population-based weights and advanced statistical measures, this analysis offers valuable insights into the effectiveness of waste management strategies and highlights regions that may need additional focus or resources.

4.2. Data Analysis

The data analysis for the "Landfill Analytical: Hungary 2022-2023" project focuses on an in-depth examination of waste management across various NUTS2 regions in Hungary. This analysis is facilitated by a user interface developed to visualize the data through 80 distinct charts, each providing a detailed look into different aspects of waste management. The project's integration of technology and statistical methods offers a comprehensive understanding of waste patterns and management efficiency.

The user interface, developed using Node.js, JavaScript, CSS, and HTML, serves as a dynamic platform for data visualization. It allows users to interact with the data through various charts and tables, enhancing the accessibility and understanding of complex waste management data.

- **Chart Features:** Each chart represents a specific aspect of waste management, such as a particular campaign (e.g., Summer 2023), waste stream (e.g., Selective Municipal Solid Waste), and waste component (e.g., Food waste). The X-axis of these charts represents the NUTS2 regions, while the Y-axis shows the component content in C[%m/m] (percentage by mass).
- **Corrected Standard Deviation and Variance:** A unique feature of these charts is the inclusion of the Corrected Standard Deviation for each NUTS2 region and overall for Hungary. This statistical measure provides insights into the variability of waste components across different regions. Additionally, the variance for each component is also displayed, offering a deeper understanding of the distribution of waste types.
- **Consistency in Scale:** All charts are created with the same scale, ensuring consistency and comparability across different data visualizations.

The Data Table and Export Functionality:

- **Data Table:** The interface also includes a data table for each Excel file, detailing the data for each year, season, and category. This tabular representation allows for a detailed and structured view of the data.
- **Export to Word:** Users have the option to export these charts to a Word file, facilitating ease of sharing and reporting.

The Website and Accessibility:

- **Development and Deployment:** The website, developed using Node.js, serves as a bridge between the MongoDB database and the frontend, ensuring efficient data processing and visualization.
- **Static Data Version:** A lite version of the website, which contains static data and does not require database connectivity, has been made available on a GitHub repository (<https://github.com/aladdinAlmarashly/landfillAnalyticalHungaryMid2022Mid2023>). This version is particularly useful for quick access and dissemination.



Figure 4 QR Code for GitHub repository

- **Public Accessibility:** The website is designed to make waste management data publicly accessible, encouraging community engagement and awareness. It serves as a platform for stakeholders, policymakers, and the general public to gain insights into waste management practices in Hungary.

The data analysis, enabled by the user interface, provides critical insights into waste management practices across Hungary. It helps identify regional disparities in waste management efficiency, the effectiveness of segregation practices, and areas where interventions may be necessary. The integration of technology and statistical analysis in this project sets a precedent for how data-driven approaches can enhance waste management strategies and policy development.

The "Landfill Analytical: Hungary 2022-2023" project's data analysis component, through its advanced user interface and comprehensive visualization tools, offers a groundbreaking approach to understanding and managing MSW. The combination of detailed statistical analysis, technological innovation, and public accessibility makes this project a valuable tool for improving waste management practices in Hungary and potentially serves as a model for other regions.

5. Results and Discussion

The analysis of Municipal Solid Waste (MSW) management in Hungary, facilitated through a dedicated website and advanced data visualization tools like Power BI, has yielded significant insights. This section discusses the results derived from these platforms and delves into the comparative analysis of waste management practices, focusing on key observations and implications.

5.1. Insights from the Website Visualization

- **Regional Variations:** The website's visualization tools highlight notable differences in waste management practices across various NUTS2 regions. These variations are evident in the segregation efficiency, volumes of different waste streams, and the effectiveness of public cleaning and illegal dumping control measures.
- **Seasonal Trends:** The data also reveals seasonal trends in waste generation and composition. For instance, certain regions may show higher volumes of specific waste types during tourist seasons or festive periods.
- **Waste Stream Analysis:** Detailed analysis of specific waste streams, such as DRS-W and EPR-P, provides insights into the effectiveness of these systems in promoting recycling and reducing waste.

The Leveraging Power BI for Advanced Analysis is:

- **Comparative Analysis Tools:** Power BI's advanced analytical capabilities have been utilized to conduct a more nuanced comparison of waste management data. This includes comparing waste volumes, recycling rates, and the efficiency of waste segregation across different regions and time periods.
- **Visualizations and Dashboards:** The use of interactive dashboards and visualizations in Power BI allows for a more dynamic exploration of the data. Users can easily switch between different parameters, regions, and time frames to gain a comprehensive understanding of the waste management landscape.
- **Identification of Key Trends:** Through Power BI, significant trends have been identified, such as regions that are leading in recycling efforts or areas where improvements are needed in waste segregation or public cleaning.

5.2. Cases studied

5.2.1. Case 1: Comparing Between DRS-W and EPR-P Streams Across NUTS2 Regions

This case study focuses on comparing the performance of the Deposit Return System (DRS-W) and Extended Producer Responsibility (EPR-P) streams across different NUTS2 regions in

Hungary. The comparison is based on the percentage contribution to the total waste managed under each stream in these regions.

Comparing Between DRS-W and EPR-P Streams Across NUTS2 Regions

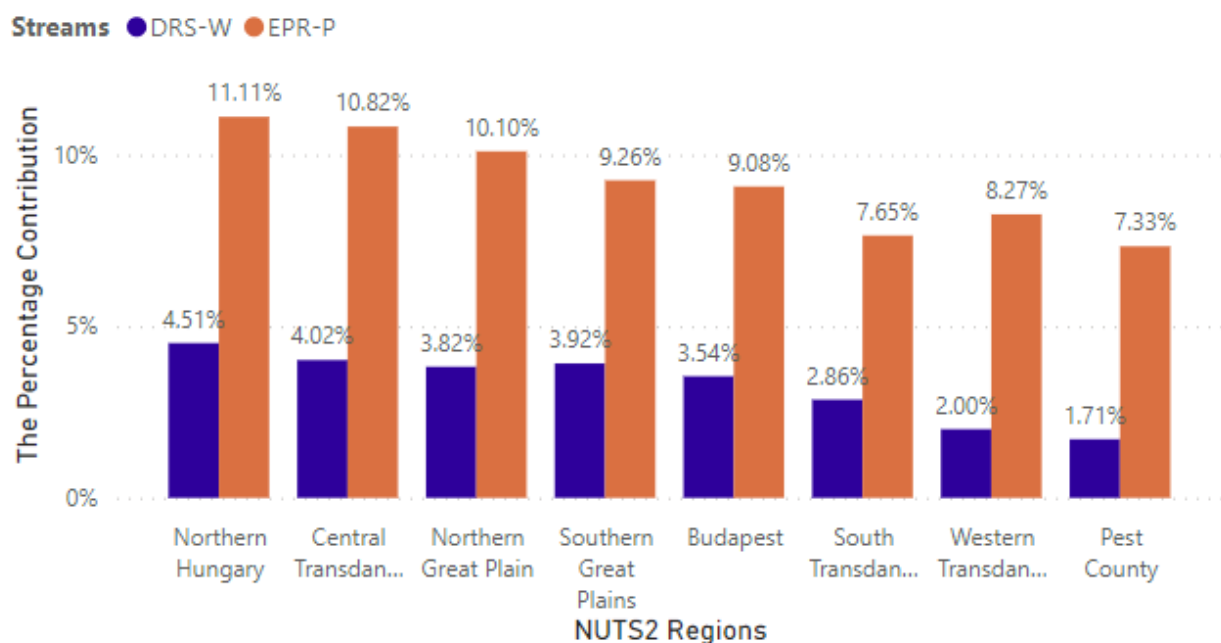


Figure 5 Comparing Between DRS-W and EPR-P Streams Across NUTS2 Regions

NUTS2 Regions	EPR-P	DRS-W
Northern Hungary	11.11%	4.51%
Central Transdanubia	10.82%	4.02%
Northern Great Plain	10.10%	3.92%
Southern Great Plain	9.26%	3.82%
Budapest	9.08%	3.54%
Western Transdanubia	8.27%	2.86%
South Transdanubia	7.65%	2.00%
Pest County	7.33%	1.71%

Table 2 Comparing between DRS-W and EPR-P Streams Across NUTS2 Regions

The data presents a clear distinction between the performance of the EPR-P and DRS-W streams across the NUTS2 regions:

1. EPR-P Stream

- The highest percentage contribution is observed in Northern Hungary (11.11%), followed closely by Central Transdanubia (10.82%), and Northern Great Plain (10.10%).
- The lowest contributions within the EPR-P stream are from South Transdanubia (7.65%) and Pest County (7.33%).

2. DRS-W Stream

- The contribution is significantly lower compared to EPR-P, with Northern Hungary again leading (4.51%), followed by Central Transdanubia (4.02%) and Southern Great Plain (3.92%).
- The lowest contributions in the DRS-W stream are from Western Transdanubia (2.00%) and Pest County (1.71%).

Regional Variations: The data indicates significant regional variations in both EPR-P and DRS-W streams. Northern Hungary consistently shows higher contributions in both streams, suggesting more effective waste management practices or higher waste generation in this region.

EPR-P vs. DRS-W: The EPR-P stream shows a higher percentage contribution across all regions compared to DRS-W. This could be indicative of the broader scope of waste types and sources under the EPR-P stream or higher efficiency in the collection and processing of EPR-P waste.

Influence of Urbanization and Population Density: The variations in contributions between regions like Budapest (with higher urbanization) and others could be attributed to factors like population density, public awareness, and the availability of waste management infrastructure.

As an Implications

- **Need for Targeted Strategies:** Regions with lower contributions in both streams, especially in the DRS-W stream, may require targeted interventions to enhance waste collection and recycling practices.
- **Policy and Infrastructure Development:** The disparities between regions call for tailored policy development and infrastructure improvements, particularly in regions lagging in waste management efficiency.
- **Community Engagement and Awareness:** Raising public awareness and engagement in waste management, particularly in regions with lower contributions, is essential for improving the effectiveness of EPR and DRS systems.

The comparative analysis between the EPR-P and DRS-W streams across NUTS2 regions reveals significant variations and highlights the need for region-specific strategies in waste management. Understanding these disparities is crucial for developing effective policies and interventions to enhance waste management practices across Hungary.

5.2.2. Case 2: Comparing Between Streams and NUTS2 Regions

This case study focuses on a comparative analysis of different waste management streams (EPR-P, Plastic, Bio, DRS-W, Food) across NUTS2 regions in Hungary. The comparison is based on the percentage contribution to the total waste managed under each stream in these regions.

Comparing Between Streams and NUTS2 Regions

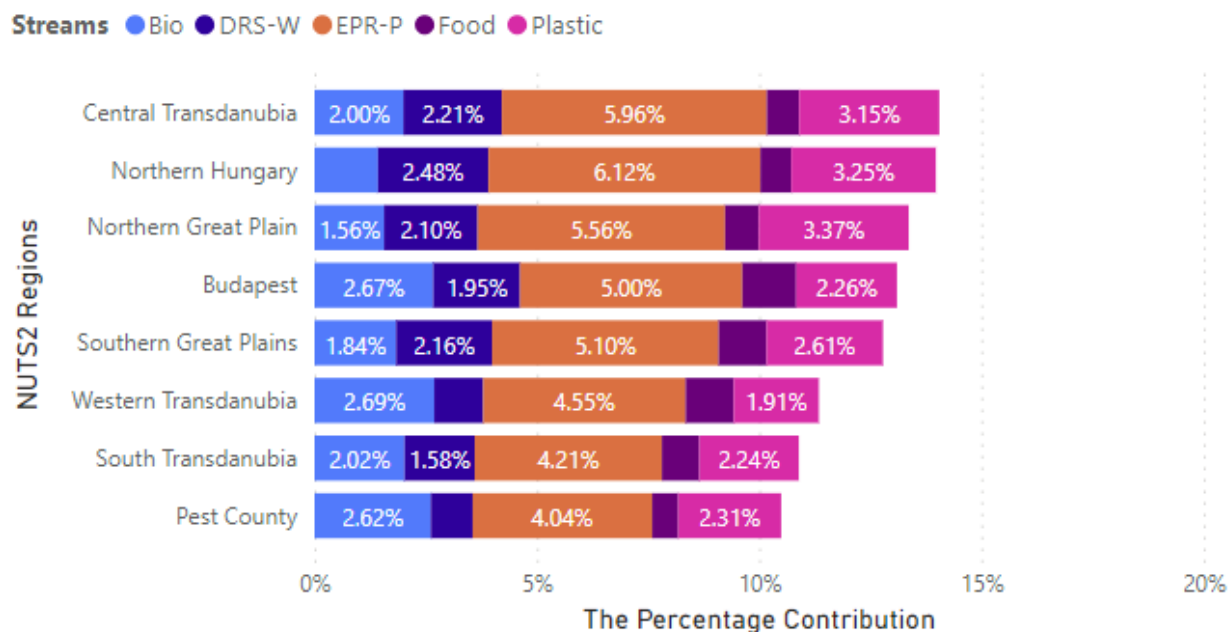


Figure 6 Comparing Between Streams and NUTS2 Regions

	EPR-P	Bio	Plastic	DRS-W	Food
Budapest	5.00%	2.67%	2.26%	1.95%	1.21%
Central Transdanubia	5.96%	3.15%	2.21%	2.00%	0.73%

Northern Great Plain	5.56%	3.37%	2.10%	1.56%	0.76%
Northern Hungary	6.12%	3.25%	2.48%	1.43%	0.69%
Pest County	4.04%	2.62%	2.31%	0.94%	0.59%
South Transdanubia	4.21%	2.24%	2.02%	1.58%	0.84%
Southern Great Plain	5.10%	2.61%	2.16%	1.84%	1.08%
Western Transdanubia	4.55%	2.69%	1.91%	1.10%	1.08%

Table 3 Comparing Between Streams and NUTS2 Regions

The data presents a detailed comparison across various waste streams and regions:

1. EPR-P Stream:

- Northern Hungary leads with 6.12%, followed by Central Transdanubia at 5.96% and Northern Great Plain at 5.56%.
- The lowest EPR-P contributions are observed in South Transdanubia (4.21%) and Pest County (4.04%).

2. Plastic Stream:

- Northern Great Plain shows the highest percentage of Plastic waste (3.37%), followed by Northern Hungary (3.25%) and Central Transdanubia (3.15%).
- Lower contributions are noted in Pest County (2.31%) and Budapest (2.26%).

3. Bio Stream:

- Western Transdanubia leads in Biowaste with 2.69%, closely followed by Budapest at 2.67% and Pest County at 2.62%.
- The lowest contributions in Biowaste are seen in Northern Hungary (1.43%) and Northern Great Plain (1.56%).

4. DRS-W Stream:

- Northern Hungary contributes 2.48% to the DRS-W stream, with Central Transdanubia at 2.21% and Southern Great Plain at 2.16%.
- Lower contributions are observed in Western Transdanubia (1.10%) and Pest County (0.94%).

5. Food Stream:

- Budapest leads in Food waste with 1.21%, followed by Western Transdanubia (1.08%) and Southern Great Plain (1.08%).
- Lesser contributions are from Pest County (0.59%) and Central Transdanubia (0.73%).

Regional Variations: The data indicates considerable regional variations in waste management across different streams. This could be due to factors such as the effectiveness of waste management policies, public awareness, and infrastructure availability in different regions.

Stream Popularity: EPR-P stream shows significant contributions across all regions, indicating its widespread adoption and effectiveness. The Plastic and Bio streams also show notable contributions but vary more significantly across regions.

Challenges in Waste Streams: Certain streams like DRS-W and Food waste show lower contributions in some regions, suggesting potential areas for policy intervention and increased focus on waste segregation and recycling efforts.

As an Implications

- **Policy Focus:** Regions with lower contributions in certain streams may need targeted policies to improve waste management practices, particularly in streams like DRS-W and Food waste.
- **Infrastructure and Awareness:** Enhancing waste management infrastructure and public awareness campaigns in regions with lower contributions could significantly improve waste management efficiency.
- **Best Practices Sharing:** Regions with higher contributions in specific streams can serve as benchmarks, sharing best practices and strategies with other regions.

The comparative analysis across different waste streams and NUTS2 regions provides valuable insights into the effectiveness of waste management practices in Hungary. Understanding these variations is crucial for developing targeted strategies to enhance waste segregation, recycling rates, and overall waste management efficiency across the country.

5.2.3. Case 3: Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Plastic Stream

This case study involves a comparative analysis of different waste categories (Illegally Deposited, Mixed Municipal Solid Waste (MSW), Public Cleaning, and Selective Municipal Solid Waste (SMSW)) across different seasons in 2022 and 2023 for Hungary. The focus is on understanding how the contribution of these categories varies seasonally, with a specific lens on the plastic stream.

Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Plastic Stream

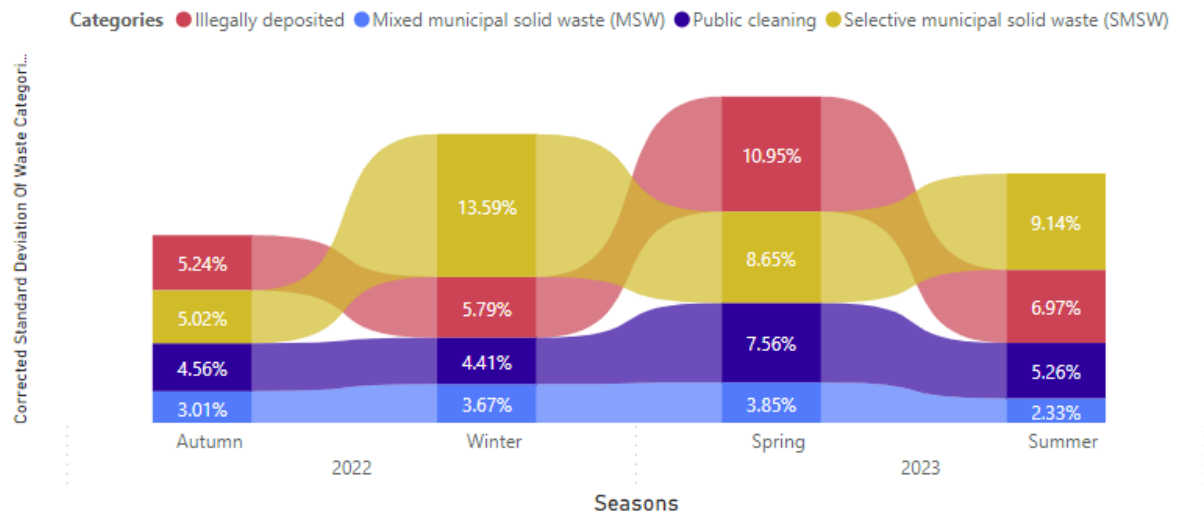


Figure 7 Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Plastic Stream

Year	Season	Corrected Sample Standard Deviation	Category
2022	Autumn	5.24%	Illegally deposited
2022	Autumn	3.01%	Mixed municipal solid waste (MSW)
2022	Autumn	4.56%	Public cleaning
2022	Autumn	5.02%	Selective municipal solid waste (SMSW)
2022	Winter	5.79%	Illegally deposited
2022	Winter	3.67%	Mixed municipal solid waste (MSW)
2022	Winter	4.41%	Public cleaning
2022	Winter	13.59%	Selective municipal solid waste (SMSW)
2023	Spring	10.95%	Illegally deposited
2023	Spring	3.85%	Mixed municipal solid waste (MSW)
2023	Spring	7.56%	Public cleaning
2023	Spring	8.65%	Selective municipal solid waste (SMSW)
2023	Summer	6.97%	Illegally deposited
2023	Summer	2.33%	Mixed municipal solid waste (MSW)

2023	Summer	5.26%	Public cleaning
2023	Summer	9.14%	Selective municipal solid waste (SMSW)

Table 4 Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Plastic Stream

The data indicates significant seasonal variations across the different waste categories:

1. Illegally Deposited Waste:

The highest contribution is observed in Spring 2023 (10.95%), indicating an increase in illegal dumping activities during this season. Autumn 2022 and Summer 2023 also show relatively high percentages (5.24% and 6.97%, respectively).

2. Mixed MSW:

The contribution to Mixed MSW is relatively consistent across seasons, with a slight peak in Winter 2022 (3.67%) and Spring 2023 (3.85%). The lowest contribution is in Summer 2023 (2.33%).

3. Public Cleaning:

Public cleaning activities peak in Spring 2023 (7.56%), suggesting either increased public activities or enhanced cleaning efforts during this season. Winter 2022 and Summer 2023 also show notable contributions (4.41% and 5.26%, respectively).

4. Selective MSW (SMSW):

A significant peak in SMSW contribution is observed in Winter 2022 (13.59%), possibly indicating heightened recycling and segregation activities. Spring 2023 and Summer 2023 also show considerable contributions (8.65% and 9.14%, respectively).

Seasonal Impact on Waste Categories: The data reveals a clear seasonal impact on various waste categories. Factors such as weather conditions, public holidays, and seasonal events might influence these variations.

Increased Illegal Dumping in Spring: The spike in illegally deposited waste in Spring 2023 warrants further investigation. It could be related to spring cleaning activities or changes in public behavior during warmer months.

Enhanced Recycling in Winter: The high percentage in SMSW during Winter 2022 suggests effective recycling and waste segregation practices, possibly influenced by seasonal awareness campaigns or municipal initiatives.

As a Implications

- Targeted Seasonal Policies: The variations across seasons indicate the need for targeted waste management policies and campaigns that align with seasonal trends and public behavior.
- Awareness and Enforcement: Increased awareness campaigns and enforcement against illegal dumping, especially in seasons with higher rates, could be beneficial.
- Infrastructure and Resource Allocation: Adjusting waste management infrastructure and resources in anticipation of seasonal changes could enhance efficiency, particularly in public cleaning and recycling efforts.

The comparative analysis of waste categories across different seasons in Hungary underscores the dynamic nature of waste management and the impact of seasonal variations. These insights are crucial for developing adaptive waste management strategies that cater to seasonal trends, enhancing the overall efficiency and effectiveness of waste management practices in Hungary.

5.2.4. Case 4 Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Plastic Stream

This comparative analysis examines the "Illegally Deposited" category within the plastic stream across different seasons (Autumn 2022, Winter 2022, Spring 2023, Summer 2023) and NUTS2 regions in Hungary. The focus is on understanding regional and seasonal variations in the percentage contribution to illegal dumping.

Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Plastic Stream

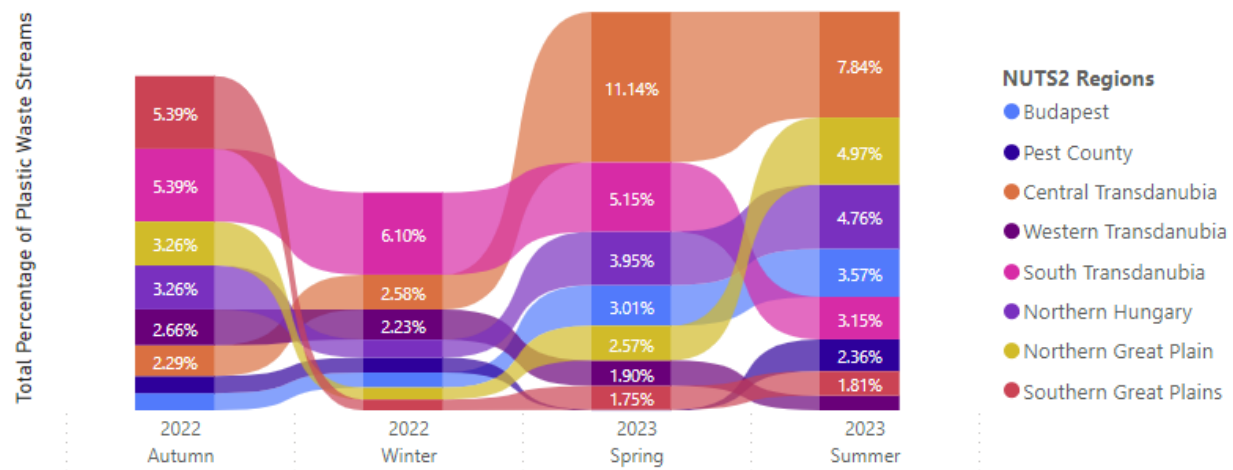


Figure 8 Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Plastic Stream

Season	Year	NUTS2 region	Total Percentage of Plastic Waste Streams
Autumn	2022	Budapest	1.27%
Autumn	2022	Pest County	1.27%
Autumn	2022	Central Transdanubia	2.29%
Autumn	2022	Western Transdanubia	2.66%
Autumn	2022	South Transdanubia	5.39%
Autumn	2022	Northern Hungary	3.26%
Autumn	2022	Northern Great Plain	3.26%
Autumn	2022	Southern Great Plain	5.39%
Winter	2022	Budapest	1.11%
Winter	2022	Pest County	1.11%
Winter	2022	Central Transdanubia	2.58%

Winter	2022	Western Transdanubia	2.23%
Winter	2022	South Transdanubia	6.10%
Winter	2022	Northern Hungary	1.33%
Winter	2022	Northern Great Plain	0.88%
Winter	2022	Southern Great Plain	0.80%
Spring	2023	Budapest	3.01%
Spring	2023	Pest County	0.04%
Spring	2023	Central Transdanubia	11.14%
Spring	2023	Western Transdanubia	1.90%
Spring	2023	South Transdanubia	5.15%
Spring	2023	Northern Hungary	3.95%
Spring	2023	Northern Great Plain	2.57%
Spring	2023	Southern Great Plain	1.75%
Summer	2023	Budapest	3.57%
Summer	2023	Pest County	2.36%
Summer	2023	Central Transdanubia	7.84%
Summer	2023	Western Transdanubia	1.09%
Summer	2023	South Transdanubia	3.15%
Summer	2023	Northern Hungary	4.76%
Summer	2023	Northern Great Plain	4.97%
Summer	2023	Southern Great Plain	1.81%

Table 5 Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Plastic Stream

The data highlights notable variations both seasonally and regionally:

1. Autumn 2022:
 - The highest percentages of illegal dumping in the plastic stream are observed in South Transdanubia and Southern Great Plain, both at 5.39%.
 - Central Transdanubia and Western Transdanubia also show relatively high rates (2.29% and 2.66%, respectively).
2. Winter 2022:
 - South Transdanubia leads with 6.10%, followed by Central Transdanubia at 2.58%.
 - Lower rates are seen in Budapest and Pest County, both at 1.11%.
3. Spring 2023:
 - Central Transdanubia shows a significant increase to 11.14%.
 - South Transdanubia and Northern Hungary also have higher rates (5.15% and 3.95%, respectively).
4. Summer 2023:

- Central Transdanubia remains high at 7.84%, with Northern Great Plain at 4.97%.
- Budapest shows an increase to 3.57%.

Seasonal Trends: The increase in illegal dumping in Spring and Summer could be attributed to increased outdoor activities and possibly less vigilance in waste management.

Regional Differences: The consistently high percentages in regions like Central Transdanubia and South Transdanubia may indicate regional challenges in waste management infrastructure or public awareness.

Policy and Enforcement Gaps: The data suggests potential gaps in policy implementation or enforcement in regions with higher percentages, particularly during Spring and Summer.

As an Implications

- Targeted Interventions: Regions with higher illegal dumping rates may require targeted interventions, including enhanced public awareness campaigns and stricter enforcement.
- Infrastructure Improvements: Improvements in waste collection infrastructure, particularly in high-contributing regions, could help reduce illegal dumping rates.
- Seasonal Strategies: Adaptation of waste management strategies to address seasonal variations could be beneficial, especially in regions with significant seasonal spikes.

The comparative analysis provides crucial insights into the challenges of managing the "Illegally Deposited" category within the plastic stream across different regions and seasons in Hungary. Understanding these variations is essential for developing targeted, effective strategies to combat illegal dumping and improve overall waste management practices.

5.2.5. Case 5: Comparative Analysis Between Seasons and Categories in Total of Hungary with a Specific Focus on Food Stream

This comparative analysis explores the distribution of the "Food" stream across various waste categories (Illegally Deposited, Mixed Municipal Solid Waste (MSW), Public Cleaning, Selective Municipal Solid Waste (SMSW)) during different seasons (Autumn 2022, Winter 2022, Spring 2023, Summer 2023) in Hungary.

Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Food Stream

Categories ● Illegally deposited ● Mixed municipal solid waste (MSW) ● Public cleaning ● Selective municipal solid waste (SMSW)

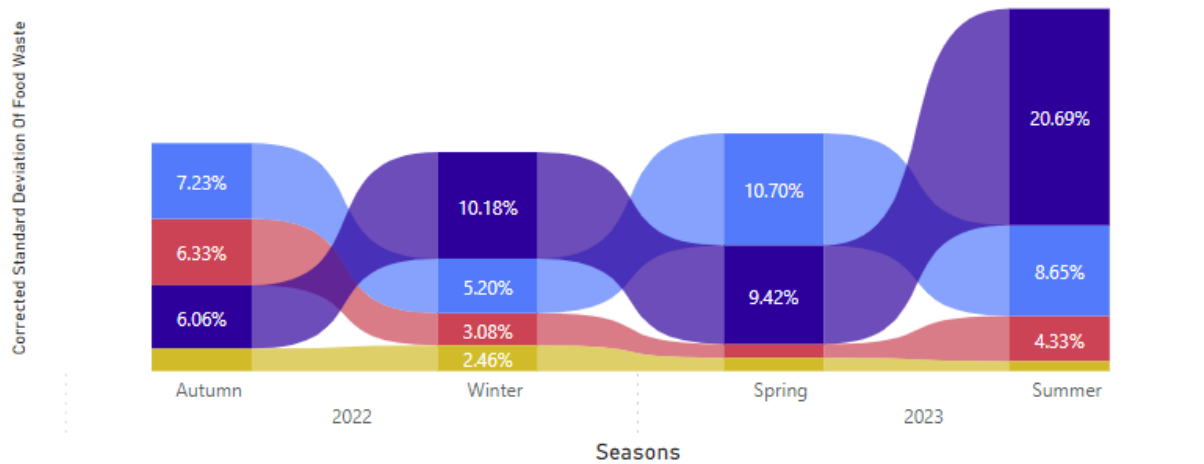


Figure 9 Comparative Analysis Between Seasons and Categories in Total of Hungary with a Specific Focus on Food Stream

Year	Season	Corrected Sample Standard Deviation	Category
2022	Autumn	6.33%	Illegally deposited
2022	Autumn	7.23%	Mixed municipal solid waste (MSW)
2022	Autumn	6.06%	Public cleaning
2022	Autumn	2.14%	Selective municipal solid waste (SMSW)
2022	Winter	3.08%	Illegally deposited
2022	Winter	5.20%	Mixed municipal solid waste (MSW)
2022	Winter	10.18%	Public cleaning
2022	Winter	2.46%	Selective municipal solid waste (SMSW)
2023	Spring	1.30%	Illegally deposited
2023	Spring	10.70%	Mixed municipal solid waste (MSW)
2023	Spring	9.42%	Public cleaning
2023	Spring	1.28%	Selective municipal solid waste (SMSW)
2023	Summer	4.33%	Illegally deposited
2023	Summer	8.65%	Mixed municipal solid waste (MSW)
2023	Summer	20.69%	Public cleaning

The data provides insights into the seasonal fluctuations in the food stream across different waste management categories:

1. Autumn 2022:

- The highest percentage is seen in Mixed MSW (7.23%), followed by Illegally Deposited waste (6.33%) and Public Cleaning (6.06%).
- SMSW has the lowest percentage (2.14%).

2. Winter 2022:

- Public Cleaning sees a significant increase to 10.18%.
- Mixed MSW and Illegally Deposited waste contribute 5.20% and 3.08%, respectively.
- SMSW shows a slight increase to 2.46%.

3. Spring 2023:

- Mixed MSW peaks at 10.70%, with Public Cleaning also high at 9.42%.
- Illegally Deposited waste decreases to 1.30%.
- SMSW contributes 1.28%, showing a decline.

4. Summer 2023:

- Public Cleaning reaches the highest percentage for any category across all seasons (20.69%).
- Mixed MSW also increases to 8.65%.
- Illegally Deposited waste and SMSW contribute 4.33% and 0.93%, respectively.

Seasonal Variation: The data indicates significant seasonal variation in the management of the food stream. The increase in Public Cleaning during Summer 2023 could be attributed to heightened outdoor activities leading to more food waste in public spaces.

SMSW Trends: The generally lower percentages in SMSW across all seasons suggest potential challenges or opportunities in the segregation and collection of food waste for recycling or composting.

Mixed MSW and Illegal Dumping: The fluctuations in Mixed MSW and Illegally Deposited waste categories might reflect changes in consumer behavior and waste management practices across different seasons.

As an Implications

- Enhanced Public Cleaning in Summer: The data suggests the need for increased resources and strategies for public cleaning during the summer months.
- SMSW Promotion: There is a need to promote and facilitate the segregation of food waste into the SMSW stream, perhaps through awareness campaigns and improved segregation facilities.
- Policy Adjustments: Seasonal adjustments to waste management policies and practices, particularly for Mixed MSW and Illegally Deposited categories, could enhance overall waste management efficiency.

This analysis highlights the importance of considering seasonal variations in waste management strategies, particularly for the food stream. The insights gained from this comparative analysis can guide policymakers and waste management authorities in Hungary to tailor their strategies and resources according to seasonal needs and trends, thereby improving the overall efficiency and effectiveness of waste management.

5.2.6. Case 6: Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Food Stream

This case study provides a comparative analysis of the "Illegally Deposited" category within the food stream across different seasons (Autumn 2022, Winter 2022, Spring 2023, Summer 2023) and NUTS2 regions in Hungary. The analysis is based on the percentage contribution to the total of illegally deposited food waste in each region.

Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Public Cleaning" Category in the Food Stream

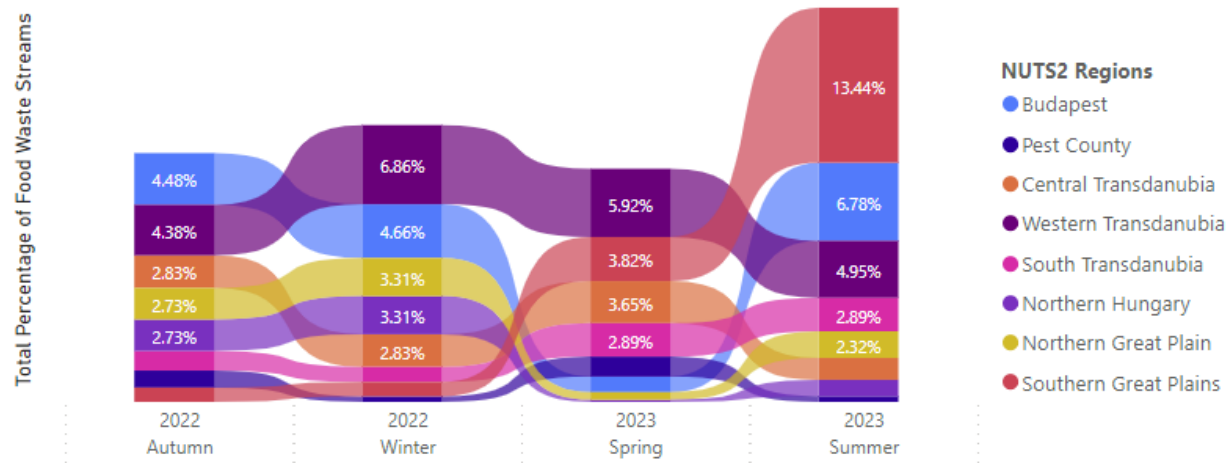


Figure 10 Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Food Stream

Season	Year	NUTS2 region	Total Percentage of Food Waste Streams
Autumn	2022	Budapest	4.48%
Autumn	2022	Pest County	1.48%
Autumn	2022	Central Transdanubia	2.83%
Autumn	2022	Western Transdanubia	4.38%
Autumn	2022	South Transdanubia	1.70%
Autumn	2022	Northern Hungary	2.73%
Autumn	2022	Northern Great Plain	2.73%
Autumn	2022	Southern Great Plain	1.24%
Winter	2022	Budapest	4.66%
Winter	2022	Pest County	0.49%
Winter	2022	Central Transdanubia	2.83%

Winter	2022	Western Transdanubia	6.86%
Winter	2022	South Transdanubia	1.31%
Winter	2022	Northern Hungary	3.31%
Winter	2022	Northern Great Plain	3.31%
Winter	2022	Southern Great Plain	1.24%
Spring	2023	Budapest	1.35%
Spring	2023	Pest County	1.74%
Spring	2023	Central Transdanubia	3.65%
Spring	2023	Western Transdanubia	5.92%
Spring	2023	South Transdanubia	2.89%
Spring	2023	Northern Hungary	0.19%
Spring	2023	Northern Great Plain	0.66%
Spring	2023	Southern Great Plain	3.82%
Summer	2023	Budapest	6.78%
Summer	2023	Pest County	0.50%
Summer	2023	Central Transdanubia	1.90%
Summer	2023	Western Transdanubia	4.95%
Summer	2023	South Transdanubia	2.89%
Summer	2023	Northern Hungary	1.41%
Summer	2023	Northern Great Plain	2.32%
Summer	2023	Southern Great Plain	13.44%

Table 7 Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally Deposited" Category in the Food Stream

The data reveals both seasonal and regional variations in the illegally deposited food stream:

1. Autumn 2022:
 - Budapest and Western Transdanubia show higher percentages (4.48% and 4.38%, respectively).
 - Lower rates are observed in Southern Great Plain (1.24%) and South Transdanubia (1.70%).
2. Winter 2022:
 - An increase is seen in Budapest (4.66%) and Western Transdanubia (6.86%).
 - Southern Great Plain and Pest County record lower contributions (1.24% and 0.49%, respectively).
3. Spring 2023:
 - Western Transdanubia leads with 5.92%, followed by Central Transdanubia at 3.65%.
 - Significantly lower percentages are noted in Northern Hungary (0.19%) and Northern Great Plain (0.66%).
4. Summer 2023:

- The highest percentage is observed in the Southern Great Plain (13.44%) and Budapest (6.78%).
- Lower contributions are seen in Pest County (0.50%) and Central Transdanubia (1.90%).

Seasonal Influence: The data indicates that seasonal factors significantly influence the illegal dumping of food waste, with notable increases in specific regions during certain seasons.

Regional Disparities: There are evident disparities among regions, with areas like Budapest and Western Transdanubia consistently showing higher rates of illegal food waste deposition.

Summer Spike in Southern Great Plain: The dramatic increase in Southern Great Plain during Summer 2023 warrants further investigation and could be related to specific local factors or events.

As an Implications

- Targeted Enforcement and Awareness: Regions with high rates of illegal dumping, particularly during specific seasons, may require targeted enforcement efforts and public awareness campaigns.
- Infrastructure and Accessibility: Improving waste collection infrastructure and accessibility, especially in regions and seasons with high illegal dumping rates, could help mitigate this issue.
- Seasonal Adjustments in Policy: Waste management policies may need to be adjusted seasonally to address the fluctuating trends in illegal dumping, especially in regions with significant seasonal variations.

This comparative analysis between seasons and NUTS2 regions in Hungary, focusing on the "Illegally Deposited" category within the food stream, highlights the critical need for tailored strategies to address the illegal dumping of food waste. Understanding these variations is key to developing effective waste management policies and interventions that are responsive to both regional needs and seasonal changes.

6. Conclusions

My work in this project centered on evaluating and comparing Municipal Solid Waste (MSW) management across various NUTS2 regions in Hungary over different seasons has provided significant insights into the effectiveness and challenges of waste management practices. Utilizing a combination of sophisticated data visualization tools, including a custom-developed website and Microsoft Power BI, I analyzed diverse waste streams like DRS-W, EPR-P, Plastic, Bio, and Food.

The Case Study Comparisons is:

- DRS vs. EPR Streams: Showed significant regional variations in waste management, with the EPR-P stream generally having a higher percentage contribution across all regions compared to the DRS-W stream.
- Seasonal and Category Comparison: Highlighted notable seasonal fluctuations in various waste categories, indicating the impact of seasonal trends on waste generation and management.
- Regional and Seasonal Analysis: Demonstrated substantial regional differences in illegal dumping and specific waste stream management, particularly in the food stream, across different seasons.

Seasonal and Regional Variations: My analysis revealed that both regional and seasonal factors significantly influence waste management practices. Regions like Central Transdanubia and South Transdanubia showed higher rates of illegal dumping during certain seasons, indicating a potential need for targeted interventions.

Challenges in Waste Streams Management: The data pointed out specific challenges in managing different waste streams. The low contribution rates in certain streams, such as DRS-W and SMSW, in some regions suggest opportunities for improvement in waste segregation and recycling.

Public Cleaning and Illegal Dumping: The analysis underscored the need for enhanced public cleaning, particularly in summer, and more stringent measures to combat illegal dumping, especially in high-contributing regions.

Targeted Policy Interventions: The study suggests the need for region-specific policy interventions, focusing on areas lagging in certain aspects of waste management.

Infrastructure Enhancement: Improving waste collection and recycling infrastructure can significantly impact the efficiency of waste management, particularly in regions with high illegal dumping rates.

Public Awareness and Engagement: Raising awareness about waste segregation, recycling, and the consequences of illegal dumping is crucial. Regions with lower contribution rates in specific waste streams could benefit from targeted awareness campaigns and community engagement programs.

Role of Technology: The integration of advanced data analysis tools, such as Power BI, proved crucial in providing detailed insights and facilitating an understanding of complex waste management data.

Recommendations for Future Research: Future research could focus on longitudinal studies to track the impact of policy changes over time and explore the effectiveness of different waste management models in varying regional contexts.

In this project, I provide a comprehensive overview of waste management practices across Hungary, revealing critical insights into the effectiveness, challenges, and opportunities in various waste streams and regions. The findings emphasize the need for adaptive, region-specific waste management strategies that are responsive to seasonal variations and regional needs. The role of technology in enhancing waste management practices is undeniable, offering a pathway for more efficient, sustainable, and community-inclusive waste management approaches in the future.

7. Recommendations for Future Work

The following are recommendations for future work that I propose:

Longitudinal Studies: Future research should consider longitudinal studies spanning multiple years to track the evolution of waste management practices and the long-term impact of policy changes.

Expanded Data Sets: Incorporating additional data points, such as waste composition details, consumer behavior patterns, and economic factors, can provide a more comprehensive understanding of waste management dynamics.

Integration of IoT and Smart Technologies: Exploring the use of the Internet of Things (IoT) and smart technologies in waste collection and management can lead to more efficient practices. This includes smart bins, waste tracking systems, and predictive analytics for waste generation patterns.

Development of Mobile Applications: Creating mobile applications for public engagement in waste management, such as apps for waste collection schedules, recycling guidelines, and reporting illegal dumping, can enhance community participation.

Region-Specific Strategies: Developing tailored waste management strategies for different NUTS2 regions, considering their unique challenges and needs, can lead to more effective waste management.

Infrastructure Improvement: Investing in modern waste processing facilities, especially in regions with lower recycling rates or higher illegal dumping, is crucial. This also includes enhancing recycling centers and waste segregation facilities.

Educational Campaigns: Implementing continuous and targeted educational campaigns to raise public awareness about the importance of waste segregation, recycling, and the environmental impact of improper waste disposal.

Community Involvement Programs: Engaging communities through volunteer programs, waste management workshops, and local initiatives can foster a sense of responsibility and participation in waste management efforts.

Comparative Policy Analysis: Conducting comparative studies of waste management policies and practices in other countries or regions can provide valuable insights and best practices that can be adapted to the Hungarian context.

Effectiveness of Policy Instruments: Researching the effectiveness of various policy instruments, such as incentives for recycling, penalties for illegal dumping, and producer responsibility schemes, can guide future policy development.

Circular Economy Models: Exploring circular economy models in waste management to promote sustainability. This includes studies on waste-to-energy systems, material recovery facilities, and life cycle analysis of products.

Sustainability Metrics: Developing and implementing sustainability metrics and benchmarks for waste management practices to monitor progress and guide improvements.

Future work in the field of waste management should focus on technological advancements, policy and infrastructure development, public awareness, and sustainability. By addressing these areas, waste management practices can become more efficient, community-focused, and environmentally sustainable. The integration of innovative technologies, along with targeted research and policy interventions, can significantly enhance waste management systems in Hungary and beyond.

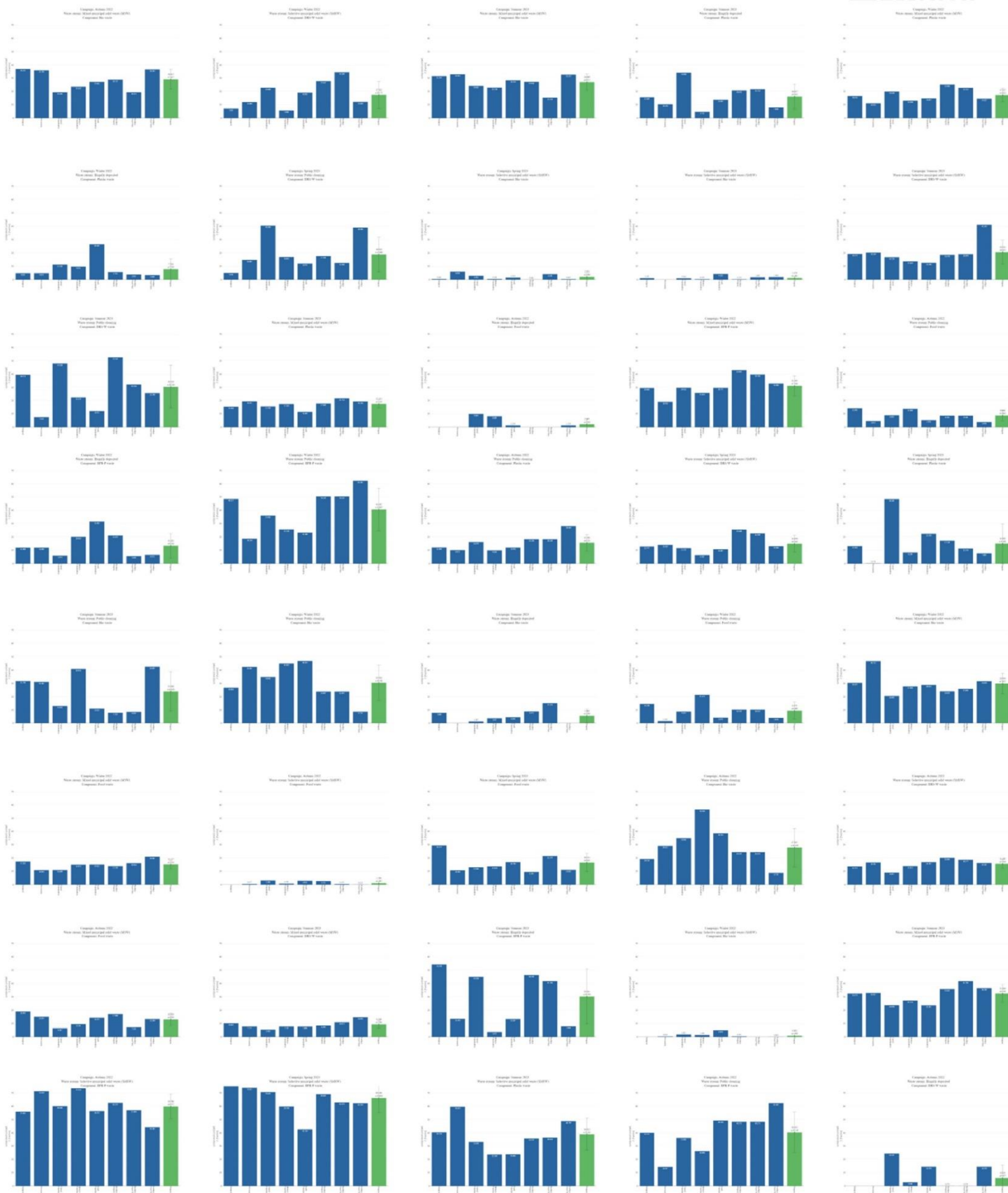
8. References

1. Depaolini A.R., Bianchi G., Fornai D., Cardelli A., Badalassi A., Cardelli C., Davoli E.: Physical and chemical characterization of representative samples of recycled rubber from end-of-life tires. *Chemosphere* 184 pp. 1320-1326. DOI: 10.1016/j.chemosphere.2017.06.093 (2017)
2. Faitli J., Romenda R.: Detailed Sampling Protocol for the Analysis of Residual Municipal Solid Wastes. In: K. Moustakas ; M. Loizidou (szerk.) *Proceedings of the 7th International Conference on Sustainable Solid Waste Management, Herakleion, Görögország 2019.06.26-29. Hellenic Mediterranean University*, pp 1-10 Session XXIII. Paper 10. (2019)
3. Maris E., Botane P., Wavrer P., Froelich D.: Characterizing plastics originating from WEEE: A case study in France. *Minerals Engineering, Elsevier*, 76, pp. 28-37. DOI: 10.1016/j.mineng.2014.12.034. hal-01206310. (2015)
4. Laubertova M., Trpcevska J., Malindzakova M.: Logistics of the Electronic Waste Sampling Procedure: The Influence of Granularity on Determination of Copper Content in PCBs. *Pol. J. Environ. Stud.* Vol. 27, No. 4. pp. 1593-1599. DOI: 10.15244/pjoes/77049. (2018)
5. Rodríguez L. S., Bermejo Muñoz J. M., Zambon A., Faure J. P.: Determination of the Biomass Content of End-of-Life Tyres. In the *Biomass Volume Estimation and Valorization for Energy*. Eds. Tumuluru J. S. Publisher: IntechOpen, DOI: 10.5772/62678 (2017)
6. Vojtonovszki-Soltész V., Faitli J.: A hazánkban keletkező kommunális hulladékok település és régió szintű, ill. a hulladékforrás típusa szerinti jellemző összetétele. In: Rákhely G., Hodúr C. (szerk.) *II. Sustainable Raw Materials Conference Book - International Project Week and Scientific Conference, Szeged, Magyarország: University of Szeged*, pp. 272-280. (2019)
7. EN 14243 - Materials obtained from End-of-Life Tyres (ELTs), Part 1: General definitions related to the methods for determining their dimension(s) and impurities; Part 2: Granulates and powders – Methods for determining the particle size distribution and impurities, including free steel and free textile content; Part 3: Shreds, cuts and chips – Methods for determining their dimension(s) including protruding filaments dimensions.
8. Faitli J., Nagy S., Ágoston Cs., Szabó A., Szakolczai P.: EPR and DRS Based Municipal Solid Waste Analysis Seasonal Campaigns in Hungary. In: *CHANIA 2023 - 10th International Conference on Sustainable Solid Waste Management. Chania, Görögország, 2023.06.21. - 2023.06.24.* pp 1-8. Paper 3. in Session V. (2023a)
9. Faitli J., Romenda R., Nagy S.: Települési szilárd hulladékok vizsgálata és elemzési módszertanának fejlesztése. In: Faitli J. (szerk.): *100 éves a Nyersanyagelőkészítés és Környezettechnológia Intézet: Szemelvények az intézet szakmai-tudományos eredményeiből.* Miskolc: Miskolci Egyetemi Kiadó, ISBN 978-615-5626-88-3, pp. 213-232 (2023b)
10. Project name is KGEF/642/2022-TIM_SZERZ: EPR-es települési szilárdhulladék országos vizsgálati kampányok elvégzése 2022/23

Appendices

You can find this chart at the following URL

(<https://github.com/aladdinAlmarashly/landfillAnalyticalHungaryMid2022Mid2023>)

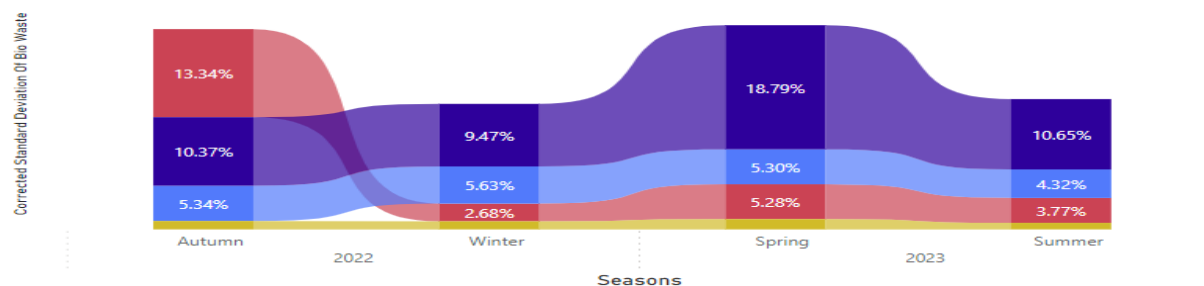


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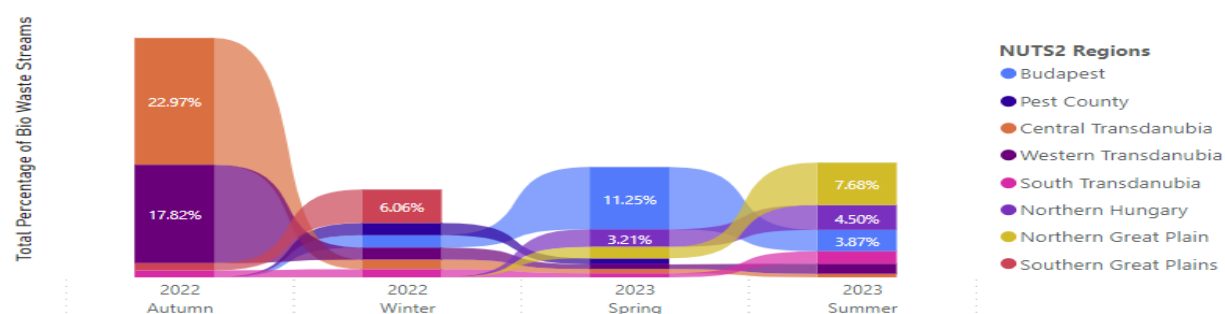


Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on Bio Stream

Categories ● Illegally deposited ● Mixed municipal solid waste (MSW) ● Public cleaning ● Selective municipal solid waste (SMSW)

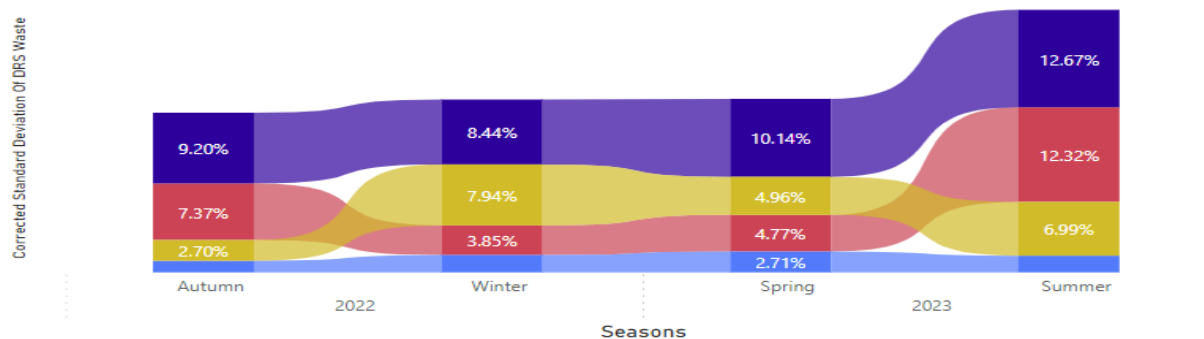


Comparative Analysis Between Seasons and NUTS2 Regions with a Focus on the "Illegally deposited" Category in the Bio Stream



Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on DRS Stream

Categories ● Illegally deposited ● Mixed municipal solid waste (MSW) ● Public cleaning ● Selective municipal solid waste (SMSW)



Comparing Between Seasons and Categories in Total of Hungary with a Specific Focus on ERP Stream

Categories ● Illegally deposited ● Mixed municipal solid waste (MSW) ● Public cleaning ● Selective municipal solid waste (SMSW)

