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ANALYSIS OF MUNICIPAL WASTE MANAGEMENT PROBLEMS ON THE BASE OF THE SILESIA VOIVODESHIP ENTERPRISE

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Purpose: The main aim of the research presented in this article was identification and analyzation the logistical problems occurred in municipal waste management and their impact on their recycling in the context of sustainable development. Additionally, the proposing of several improvements that can increase the efficiency of the waste management system. Nowadays, through the newly emerging EU directives, the increasing population and consumer lifestyle, thus the huge amounts of generated waste, the problem of waste will increase, and it will be more important to find new solutions to encourage people for recycling.
Design/methodology/approach: In the research presented in this article, an analysis of the literature and Silesia voivodeship enterprise on the processes of waste management was used; with particular emphasis on the logistics of waste collection, segregation and sorting.
Findings: The analysis highlights the need for further technological modernization and continued educational activities aimed at society to achieve higher standards in waste management. The implementation of modern technological solutions and educational activities can significantly improve the waste management process, contributing to the implementation of sustainable development and minimizing the negative impact on the environment.
Research limitations/implications: Future research will be continued in the field of municipal waste management like collection, segregation, sorting, recycling and consumers' attitude.
Practical implications: The main objective of this article was to analyze the logistic problems related to municipal waste management from the perspective of a company providing comprehensive services in the field of waste collection and management. As part of the conducted research, key challenges were identified, such as insufficient waste segregation at source and lack of precision in sorting processes.
Originality/value: Based on empirical research, the article shows the scale of the problem that, through the new EU directives on the circular economy and sustainable development, will be a forward-looking and important issue. Additionally, the article presents concepts for waste management from the industrial and consumer perspective.
Keywords: municipal waste, recycling, waste segregation, sustainable development.
Category of the paper: Research paper.

1. Introduction

Municipal waste is one of the most visible and key challenges facing contemporary society. In an era of rapidly growing population and intensive urbanization, effective management of waste has become a priority not only at the national level, but also globally. Responsible waste management is crucial for environmental protection, public health and sustainable social development. Regardless of the source of its origin, appropriate processing and minimization of municipal waste are an important element of pro-ecological strategies that aim to reduce the negative impact of humans on the planet.

Municipal waste is waste generated in households, as well as waste of a similar nature and composition that comes from other sources, such as trade, services, educational institutions, public administration or health care. The definition of municipal waste can be found in many global, European and Polish laws. In Poland, the definition used is that "municipal waste is waste generated in households and waste from other waste producers, which due to its nature and composition is similar to waste from households, in particular unsegregated (mixed) municipal waste and selective waste" (Dz.U. 2013, poz. 21). An important aspect is that this waste does not come from manufacturing activities, agriculture or sewage treatment plants. The definition of waste based on applicable legal regulations was presented by Seroka-Stolka in her article, indicating that "waste is considered to be any substance or object which the possessor disposes of, intends to dispose of or is obliged to dispose of" (Seroka-Stolka, Ślusarczyk, 2022).

The development of technology and the changing attitudes of societies towards environmental protection in the 20th and 21st centuries have led to the further development of waste management systems. Currently, many countries are introducing advanced waste separation, recycling and energy recovery systems, which contribute to reducing the burden on the natural environment. In Europe, the history of waste management has undergone a significant evolution, especially in the 20th and 21st centuries, when countries began to introduce advanced recycling and energy recovery systems. Many European countries, including Germany and Sweden, have become leaders in the field of sustainable waste management, developing modern technologies and practices that reduce the burden on the environment (Zalewska, 2019).

In Poland, the development of the waste management system quickens after accession to the European Union in 2004. The introduction of regulations in line with EU directives significantly improved waste management in the country, especially in segregation and recycling. Poland is gradually increasing the share of waste subject to recycling and introducing innovative solutions, such as waste incinerators and energy recovery systems. However, despite progress, there are still challenges related to the full implementation of European standards, especially in smaller towns and rural areas. Further investment in infrastructure and

environmental education of society are key to achieving the goals of sustainable development and effective waste management in Poland (Dz.U. 2013, poz. 21; Wengierek, 2015).

2. Conceptual background

2.1. Municipal waste definition

Waste can be classified in many ways, but the simplest division concerns the place where it is generated. According to this classification, waste can be divided into industrial and municipal waste. The first of these is waste from industrial plants or factories. Municipal waste is generated by households or other places where waste with a similar composition is generated, e.g. offices or scientific institutions (Lipińska, 2016). To organize waste management, a waste catalog was created, considering its source, main components and properties. Municipal waste is described by using a 6-digit code, the first two digits of the code represent the waste group, the next two their subgroup, and the last two the type of waste. The 6-digit waste code in the catalog for municipal waste is 20 00 00 (Lutek, 2020; BDO, 2025).

One of the key assumptions in waste management is the waste hierarchy, defined by the European Commission (Figure 1). This hierarchy is the basis for sustainable waste management and defines priorities for actions aimed at minimizing their negative impact on the environment. Waste prevention comes first, followed by reuse, recycling, recovery (including energy recovery), and finally disposal, such as landfilling. This structure aims to promote actions that bring the greatest ecological benefits (EUR-lex, 2025).

Figure 1. Waste management hierarchy.

Source: epa.gov.pl

In waste management, proper classification of waste plays a key role, providing the foundation for effective segregation and further processing. Precise determination of the type and origin of waste is the first stage in the complex process of waste management, which enables effective use of recycling and disposal technologies. Due to proper classification, it is possible to redirect individual waste fractions to the appropriate processes, which minimizes their storage and maximizes the recovery of secondary raw materials.

2.2.The concept of waste management

In waste management, proper classification of waste plays a key role, providing the foundation for effective segregation and further processing. Precise determination of the type and origin of waste is the first stage in the complex process of waste management, which enables effective use of recycling and disposal technologies. Due to proper classification, it is possible to redirect individual waste fractions to the appropriate processes, which minimizes their storage and maximizes the recovery of secondary raw materials. The main goals of properly conducted waste management are: maintaining cleanliness and order, protecting the natural environment, economical management of raw materials and natural resources and economical management of land (Hordyńska, 2017).

The concept of waste segregation the allocation of waste to a given group, in which there is a material from which the waste is made. According to the definition contained in the book "Logistics of waste management: ecologist, municipal and medical waste", segregation is the process of selecting and separating waste according to specific features that this waste has. The segregation process itself can be divided into three groups: manual segregation, mechanical segregation and automatic segregation.

The first of them is segregation consisting of separating components that allow for reuse. It is segregation of materials such as: glass, paper, plastics or steel. This segregation is performed by company employees using specialist machines not adapted to this segregation. Mechanical segregation is performed by machines located in the factory; such segregation is performed for two fractions:

- Heavy fraction (metals, glass, stones, rubble, organic and biological parts).
- Light fraction (plastic, paper, textiles).

In this part of the segregation, reuse is not used, which is the biggest difference between the first two segregation groups. In automatic segregation, mixed waste is segregated by its properties (Sidełko, 2017).

Waste segregation plays a fundamental role in sustainable waste management and environmental protection. It enables the effective separation of raw materials that can be reused from those that require disposal. Thanks to proper segregation, waste is directed to the appropriate treatment processes. Waste treatment is a key element of modern waste management, the aim of which is to minimize the negative impact on the environment and to

use resources efficiently. This process includes various technologies and methods that allow waste to be transformed into secondary raw materials, energy or other products suitable for reuse (Rozporządzenie 1, 2018).

Waste processing reduces the amount of waste going to landfill, which limits the emission of harmful substances and supports the development of a sustainable economy. Waste processing is understood as the process of recovery or disposal, including preparation prior to recovery or disposal. If waste does not go to landfill, it can be subjected to various processing methods, such as (Bauman-Kaszubska, 2017):

- Incineration.
- Gasification.
- Composting.
- Melting.
- Shredding.
- Fermentation.
- Compaction.
- Recycling.
- Separation.
- Use in agriculture.
- Chemical processing.

Of the listed methods, the most well-known and commonly used methods of waste processing are recycling, composting and incineration. The recycling process involves reprocessing waste into new products. The subject of recycling can be various wastes, including machines or devices that are no longer suitable for use. The definition of recycling includes the reprocessing of organic material (so-called organic recycling) but does not include energy recovery or the processing of materials intended for fuels or for filling excavations.

Recycling plays an important role because it allows the reuse of raw materials, which has a positive impact on the environment. The following types of recycling can be distinguished (Świątkowska, 2017):

- By type of waste:
  - Raw material - involves processing waste into raw materials that can be reused to produce a given product.
  - Material - converting waste into new products with a similar use.
  - Energy - processing waste into energy fuel that can be used to generate energy.
- By degree of processing:
  - First-degree recycling - reuse of entire, homogeneous products.
  - Second-degree recycling - recovery of parts or elements from used products.
  - Third-degree recycling - recovery of individual materials that the waste contains.

The second use of waste is composting. This is a process in which dead organic matter occurs, made available using microorganisms in use. This can be understood as organic packaging. We use it to create compost, which is available for the use of natural fertilizers. Composting the main key in waste management, according to Rosik-Dulewska, composting must take precedence over waste storage in a landfill or other method of disposal (Rosik-Dulewska, 2015).

Another popular processing method is waste combustion. Waste combustion is used for materials that cannot be reused. This process allows energy to be generated by burning them, which allows energy to be recovered in the form of heat or electricity. Waste processing is a key element of modern waste management, which includes various methods aimed at efficient use of resources and minimizing negative impacts on the environment. Recycling, composting and waste incineration are just some of the available methods for converting waste into secondary raw materials, energy or products ready for reuse. Each of these technologies plays a significant role in reducing the amount of waste going to landfills, reducing harmful emissions and supporting the development of a sustainable economy. Implementing effective waste processing processes is therefore a necessary step towards a more ecological and responsible resource management society that strives for maximum recovery of raw materials and minimizing negative impacts on the natural environment.

2.3. IT systems and technologies related to the municipal waste management

IT systems are a very important aspect in waste management, which aim to optimize the management of processes related to their collection, transport, segregation and recycling. The requirements that local government units must meet are specified in the Act of 13 September 1996 on maintaining cleanliness and order in municipalities, some of them were shown in Figure 2. Waste flow management includes procedures such as:

- Waste management planning.
- Waste collection.
- Calculation of fees.
- Waste storage.
- Waste disposal.

The Internet is the most important in waste management, as it interacts with the systems and technology found in companies. The database of products and packaging and waste management is a system based on Internet technology, enabling effective management of information related to waste management. This register came into force in 2012, where it replaced the paper version of the register with an electronic one. Mobile applications are becoming increasingly popular these days, which are used to remind residents about waste collection, and indicate which waste is being collected (Brzeszczak, 2017).

Figure 2. Selected requirements of an IT system for waste management.

Source: own work based on: Brzeszczak, 2017.

In waste management technology, various methods of waste identification are used. One of this method is barcodes, which act as an identifier, allowing reading of specific information about a given waste. Marking waste with barcodes significantly increases the efficiency of the waste management system, while also enabling control and monitoring of selective collection.

Due to automatic data entry into IT systems, the risk of errors made by employees is eliminated. Another method used in waste marking is RFID technology, which involves the use of radio waves to send information. RFID technology is also used in waste management, which uses radio waves to record and read information, which allows for quick and effective tracking of waste. The last method that can be encountered is the use of GPS systems, which involve monitoring vehicles transporting waste or containers. Technologies and systems enable continuous improvement and monitoring of waste management, which allows for more precise segregation and recycling, supporting sustainable development. Additionally, they support environmental protection and increase the effectiveness of the entire waste management system (Chomiak-Orsa, 2016; Małachowski, 2019).

3. Problems with municipal waste management in selected enterprise

The municipal waste industry is one of the key sectors of the economy, having a significant impact on the natural environment and the quality of life of residents. According to data from the Central Statistical Office, a total of 53 658 686.95 tons of municipal waste was collected in Poland in 2020–2023, which is presented in Figure 3 illustrating the amount of waste in individual years.

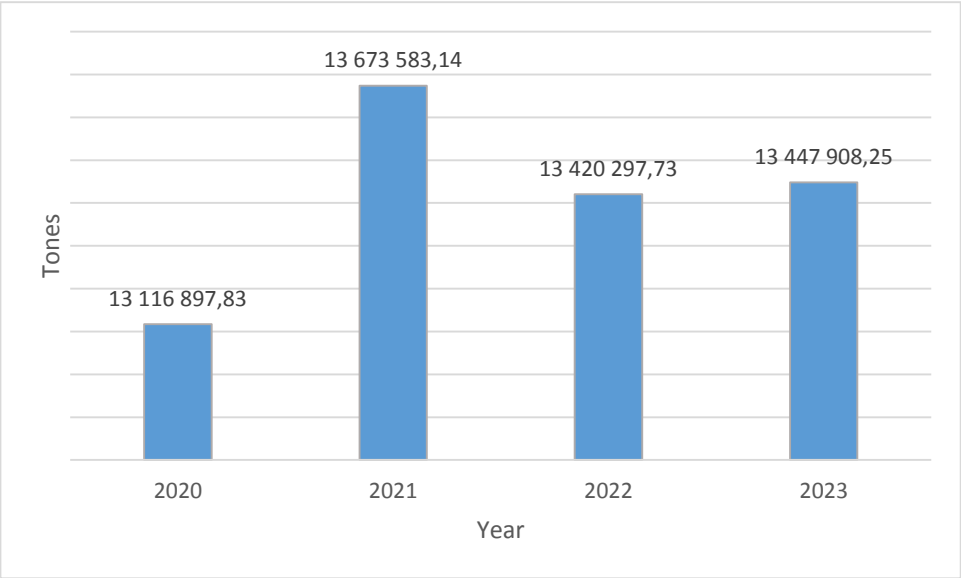

Figure 3. The amount of collected municipal waste in Poland in 2020-2023.

Source: Own work based on: Stat.gov.

Data analysis indicates a general stabilization of municipal waste in recent years, but it still occurs at a relatively high level. Such information provides valuable information on the challenges related to waste management. In addition to the total amount of waste, the level of waste segregation is also important, which directly affects the productivity of recycling and recovery of raw materials. Another important aspect is the ratio of the amount of waste collected selectively to the total amount of waste. Figure 4 shows the percentage share of waste collected selectively in relation to the total amount of waste in 2020-2023 in all of Poland.

The analyzed company is a Polish municipal company located in the Silesia region, which holds 90% of the shares, while the remaining 10% belongs to the municipalities co-creating the waste management system, such as Lędziny, Chełm Śląski etc. As a municipal company, it cooperates with local governments, implementing tasks resulting from legal regulations, as well as supporting activities related to environmental protection. The company also conducts educational activities aimed at raising ecological awareness among residents and promoting sustainable practices in waste management.

Figure 4. Percentage share of selectively collected waste in relations to the total amount of waste in 2020-2023.

Source: own work, based on: Stat.gov.

The company specializes in comprehensive waste management, including collection, transport, segregation and management of municipal waste. A key element of the activity is the implementation of modern technologies, such as raw material and energy recovery systems, which supports the implementation of sustainable development assumptions. Waste collection is carried out both from households and public entities and companies operating in the service area.

3.1. Analysis of disruptions related to waste collection and transport

Transport and logistics are key aspects of the functioning of any business, especially in the waste management industry. They include activities such as developing schedules, optimizing routes and managing vehicle fleets. The efficiency of these processes directly affects the quality of services provided and operating costs.

One of the most important problems in logistics is the difficulty of adapting schedules to dynamically changing operating conditions. Unforeseen situations, such as vehicle breakdowns, difficult weather conditions or road blockages, can lead to disruptions in the implementation of waste collection plans. Such disruptions not only increase operating costs, but also reduce the efficiency of the company's operations, which can negatively affect customer satisfaction and compliance with legal regulations.

An additional challenge is the short time allocated for developing logistics schedules, which increases the risk of making mistakes and introducing less optimal solutions. As a result, this can lead to inefficient use of resources, increased transport costs and reduced quality of services provided. Effective management of logistics processes therefore requires the implementation of modern technologies, such as GPS monitoring systems and advanced route planning software, which enable faster and more precise decision-making.

3.2. Analysis of disruptions related to segregation and consumers' attitude

Another very important problem in waste management is ensuring effective segregation, both at the place of their generation and at the stage of processing in recycling plants. Source segregation, carried out by residents and companies, is a fundamental element of recycling and raw material recovery processes. Proper sorting at the stage of waste generation allows for increasing the efficiency of the entire waste management system, but the lack of environmental awareness in society and improper segregation practices can lead to a decrease in the quality of secondary raw materials obtained. Mixed or improperly segregated waste is more difficult to process and often requires additional cleaning processes, which generates higher costs and increases the time needed to prepare it for recycling.

At the processing plant level, precise waste segregation is equally important, which is carried out using manual and mechanical sorting. Manual sorting, despite the involvement of employees, often does not allow for the detection of all unwanted elements due to the limitations of human perception and fatigue. This can reduce the efficiency of the process and lead to contamination of the obtained fractions. In turn, mechanical sorting, using advanced devices such as optical, electromagnetic or vibration separators, allows for more precise separation of individual types of materials. Nevertheless, even the most modern technologies are not able to eliminate the risk of failure to detect small or specific elements, such as foils, textiles or multi-material elements.

An additional challenge is the need to adapt segregation and sorting systems to increasingly diverse waste resulting from the development of new technologies and changes in society's lifestyle. Introducing new products to the market, such as multi-material or biodegradable packaging, requires continuous modernization of infrastructure and development of innovative separation methods. Effective waste segregation management also requires educating the public about ecology and improving awareness of the principles of proper sorting. Information campaigns, training programs and appropriately designed incentive systems can significantly contribute to improving the quality of segregation at source.

At the same time, investments in modern sorting technologies and optimization of processes in processing plants are necessary to meet the growing requirements for the recovery and recycling of raw materials. The process includes monitoring the implementation of the level of over 55% recycling, in accordance with applicable European standards. In the event of failure to achieve the assumed goals, data on the causes is collected. The management team in the examined enterprise, consisting of 8 people, analyzes the collected data, identifies problems and implements corrective actions. The effectiveness of these actions is regularly monitored and assessed. In a situation where the actions bring the expected results, the process ends with success and the secondary raw materials are directed to recirculation. However, in the absence of satisfactory results, the process again moves on to the analysis of problems and development of new solutions. Unfortunately, in 72% of cases, the waste does not meet the required level of

recycling specified by European standards. Only 18% of waste reaches the required level of recycling, which indicates a very low level of waste segregation at source, and at the same time, this is a potential area for improving the current situation. Analysis of these cases indicates that to achieve success, good segregation at source and the potential use of modern sorting and recycling technologies must occur.

3.3.Analysis of disruptions related to technologies

Technological problems in waste management constitute a significant barrier to effective waste management and the achievement of circular economy goals. One of the most serious challenges is the lack of appropriately developed waste processing infrastructure. In many cases, waste disposal and recycling plants are not sufficiently equipped to effectively process various waste fractions, such as multi-material waste, electronics or biodegradable packaging. The shortage of thermal waste treatment facilities and mechanical-biological treatment plants leads to a significant portion of waste being redirected to landfills, which is contrary to the principles of sustainable development.

Equally problematic are the technological difficulties associated with waste segregation and sorting. Manual sorting, although still widely used, is time-consuming and error-prone, which reduces its dynamics. On the other hand, mechanical sorting, even when using advanced technologies such as optical, electromagnetic or vibration separators, has its limitations. It is particularly difficult to separate multi-material elements, small plastic fragments or organic waste, which negatively affects the quality of the secondary raw materials obtained. Another problem is the limited efficiency of recycling technologies. Contaminated waste, materials that are difficult to separate, such as multi-material packaging or low-quality plastics, are often not properly processed. In the case of some materials, such as PVC or polyesters, chemical recycling requires expensive and advanced technologies that are still not widely available.

The implementation of advanced technologies such as robotics, artificial intelligence or data analysis, which could revolutionize waste management, encounters barriers related to high implementation costs and insufficient staff training. Modern waste sorting robots, predictive systems for waste stream management or real-time monitoring technologies remain rare, especially in smaller enterprises. Modernization of technology also requires huge financial outlays, which is a significant challenge for many enterprises and municipalities. The costs associated with the purchase of modern machinery, construction of processing installations or implementation of monitoring systems often exceed the financial capabilities of local communities. As a result, technological limitations in waste management become a serious obstacle to the effective functioning of waste treatment systems, which negatively affects both the environment and the implementation of sustainable development policy goals.

4. Proposals for improvements to problems identified in the enterprise

4.1. Improving the process related to waste collection and transport

Very significant problem in the waste management process is the insufficient segregation of waste at its source, which significantly affects the efficiency of subsequent stages. To prevent the continued occurrence of this problem, it is crucial to introduce more readable and easily accessible information materials that will contain detailed segregation rules. Information materials should be designed in a simple, clear and intuitive way, so that the segregation rules are easy to understand for various social groups, including children, seniors and people less involved in environmental protection. One practical solution in this area is the introduction of information systems on containers, such as QR codes, which allow for quick scanning using a smartphone and obtaining detailed instructions on segregation. Because of this, users will have access to up-to-date, detailed information at any time, which will significantly facilitate proper waste management.

To increase the effectiveness of the activities, the materials should be available in various communication channels, such as social media, local press or educational meetings organized in schools and public institutions. Combining traditional educational materials with modern technologies, such as information systems on containers, will allow reaching a wide audience and significantly contribute to building ecological awareness in society.

4.2. Improving the process related to waste segregation and consumers' attitude

The key challenge related to improving the waste segregation process is the lack of motivation of customers to properly segregate waste. One of the proposed improvements is the implementation of a system of incentives for customers, e.g. offering discounts on waste fees if a given locality collects an appropriate amount of waste that meets the standards of proper segregation. This type of motivational mechanism can increase the involvement of residents, which will directly affect a higher level of recycling and a better quality of processed waste.

An additional step to improve the waste management system could be the introduction of regular communication with residents, to inform about the results of segregation in their region and the impact of their actions on the environment. Highlighting successes and achieved results can significantly increase the sense of responsibility and motivation of residents to improve the quality of segregation. One of the innovative solutions could be a mobile application that would present the level of waste segregation in real time on specific streets of a given town, allowing residents to access information about the quality of segregation in their area and compare results with other streets. The application could also include features such as a notification system reminding about the waste collection schedule, segregation rules, rankings and statistics of the best segregation results among streets, as well as a reward system for residents who achieve a high level of segregation in their region, which would additionally motivate them to take pro-

ecological actions. In that application could also be a platform through which residents could report problems related to waste collection or suggest improvements in the waste management system. Integration of modern technologies into the communication system with residents would not only increase their involvement but also allow for more transparent and effective waste management on a local scale.

4.3. Improving the process related to technologies

The problem of inaccuracy in sorting can occur in the entire process in two cases. The first concerns mechanical sorting, which is carried out using sorting machines. The second case is manual sorting performed by employees, which is a time-consuming and less precise process.

To improve the waste sorting process, a gradual process of modernization of the sorting plant can be introduced. One solution is the use of sorting robots equipped with an advanced identification system, such as artificial intelligence. These robots can segregate waste faster and more accurately compared to human work.

The use of robots will not only improve the precision of sorting but will also allow for a reduction in the number of employees involved in manual sorting. The number of employees could be reduced to one person who will monitor the work of the robots, eliminating tiredness and human errors that often occur in the case of long-term, monotonous tasks.

In addition, the introduction of robots in sorting plants would contribute to increased safety at work, eliminating the risk of employees meeting hazardous waste. Automatizaton of the process could also reduce operating costs in the long term, as the investment costs in robots can be recouped through greater sorting efficiency and higher quality of recovered raw materials. The introduction of advanced technologies will significantly improve the waste segregation process, while increasing safety and work efficiency. These technologies will also enable more precise segregation, which will directly contribute to increasing the level of recycling in the entire process.

5. Summary and conclusion

The main objective of this article was to analyze the logistic problems related to municipal waste management from the perspective of a company providing comprehensive services in the field of waste collection and management. As part of the conducted research, key challenges were identified, such as insufficient waste segregation at source and lack of precision in sorting processes. The implemented solutions, including automation of sorting using modern technologies and implementation of educational campaigns, allowed for a significant improvement in the quality of segregation and increased recycling efficiency. The obtained results indicate that the modernized waste management system contributes to lower operating

costs and increased recovery of secondary raw materials, which supports the assumptions of a circular economy. These results confirm that appropriate logistics management, supported by technologies and educational activities, can significantly increase the efficiency of the entire system. The amount of waste collected selectively in 2022 decreased by 3.0% compared to 2020 and amounted to 763.1 thousand tonnes, i.e. 44.5% of collected municipal waste (in 2020 – 44.2%). 93.5% of waste collected selectively came from households (92.1% in 2020). The waste most frequently selected by households includes biodegradable (biodegradable) – 35.6%, bulky – 15.0% and glass – 11.9% (US, 2022).

Based on the literature and the research the following conclusions can be drawn:

- Literature analysis provided detailed knowledge on the structure, classification and functioning of the municipal waste management system. Detailed familiarization with the legal regulations in force in Poland and the European Union enabled understanding of the key challenges related to waste management.
- A key element in the waste management system in the examined enterprise is the precision of sorting, both at the stage of waste segregation by customers and during its processing at the plant.
- Process analysis indicates the need for continuous improvements to meet the growing requirements and challenges in waste management.
- The introduction of educational activities, such as information campaigns, financial incentive systems for residents and clear information materials placed on containers, significantly improved the quality of waste segregation at source and increased residents' motivation to properly handle waste.
- One of the proposed improvements was the implementation of automatization of the sorting line, using sorting robots, which increased the precision and speed of waste sorting. The use of modern technologies contributed to reducing the time of segregation and reducing the number of employees involved in waste sorting.
- Another improvement was the proposal of an application that would enable better contact between residents and the company responsible for waste collection, and the markings on containers and QR codes provided detailed information on the principles of segregation, which translated into an improvement in the quality of sorting at source.
- By implementing the proposed improvements, the level of waste recycling would be higher, and the number of people involved in waste sorting would be lower, which would allow for reducing the company's expenses on employment.

The analysis highlights the need for further technological modernization and continued educational activities aimed at society to achieve higher standards in waste management. The potential of using modern tools supporting source segregation and increasing the effectiveness of recycling was also indicated. The implementation of modern technological solutions and educational activities can significantly improve the waste management process,

contributing to the implementation of sustainable development and minimizing the negative impact on the environment.

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