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# Selective Collection and Management of Biowaste from the Municipal Sector in Poland: A Review

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**Abstract:** Municipal waste management is an important aspect in the context of the environmental protection of any country. Biowaste is the dominant stream among all municipal waste in Poland (32.4% in 2020). It can be processed through recycling and recovery processes. It is also possible to dispose of it, although according to the waste hierarchy, such action should be the last option. For biowaste to be recycled, e.g., through anaerobic digestion or composting, it must have suitable properties to be processed through the processes mentioned above. This study aims to discuss the selective collection and management of biowaste from Poland's municipal sector and identify limiting factors. The paper also indicates selected aspects of possible changes in the waste management sector, considering the role of society and waste management companies. The factors limiting the collection and further use of biowaste from the municipal sector in Poland can be divided into economic, social, technical, and technological. This article refers to the situation in Poland, but some problems occur analogously in other countries. This is because the barriers limiting the selective collection and management of biowaste in many countries are similar and differ mainly in the degree of intensity and the scope they cover. Given the increasingly stringent requirements for waste management, measures must be taken to achieve the legally required levels of recycling of biowaste and to recycle it as well as possible. The development of installations for biological waste management will be crucial.

**Keywords:** biodegradable waste; biowaste; waste management; circular economy; sustainable development; smart city



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## 1. Introduction

Waste management is one of the important challenges in reducing adverse environmental changes [1,2]. As defined in the Polish Act on Waste of 14 December 2012 [3], waste means any substance or object the holder disposes of, intends to dispose of, or is obligated to dispose of. The waste generated can be divided into the industry and municipal sectors. Among municipal waste, biodegradable waste plays an important role. According to the Polish Act on Waste of 14 December 2012 [3], biodegradable waste is defined as waste that undergoes aerobic or anaerobic decomposition with the participation of microorganisms. This waste is a broad group where many substrates, such as grass, leaves, branches, peelings, spoiled vegetables, and fruits, can be mentioned. The unique role of biodegradable waste, including biowaste, is due to the quantities in which they are generated daily and their specific properties [4]. This includes the high water content and susceptibility to decomposition under the influence of microorganisms, both under aerobic and anaerobic conditions [5].

In many countries, including Poland, the waste in question is collected selectively following the Regulation of the Minister of Climate and Environment of 10 May 2021 on the method of selective collection of selected waste fractions [6]. This is supported by its properties, which allow them to be recycled or recovered relatively quickly [7]. Often, this waste is the dominant fraction of all waste from the municipal sector—both in developed

and developing countries [8]. Consequently, biowaste management is a critical component of the overall municipal waste management system [9].

There are several main directions for biowaste management. Among them are landfilling, thermal conversion, and management through recycling and recovery processes. According to the Regulation of the Ministry of Economy and Labor on the criteria and procedures for admission of waste to respective landfill types [10], the selectively collected municipal waste from group 20 (including biodegradable waste in the group of municipal waste) as defined in the waste catalog [11] undergoes classification along with other selectively collected municipal waste fractions. In accordance with Article 122, Polish Act on Waste [3], there is no possibility to landfill selectively collected biodegradable waste. This means that biogas from landfilled waste will be significantly reduced.

Another potential option is to manage municipal waste in thermal waste conversion facilities, commonly known as incinerators [12]. For several years, these installations have become increasingly popular in Poland [13]. In Poland, in 2020, there were eight installations for the thermal conversion of municipal waste. The total capacity of these installations was 1.159 million tons, and they mainly processed municipal waste and waste from municipal waste management [14]. Among the main advantages of waste disposal by incineration is the reduction of waste mass and volume. The disadvantage, however, is the lack of recovery of numerous raw materials found in the mixed municipal waste stream. Additionally, in the case of biowaste, a problem that reduces the effectiveness of this solution is the high degree of hydration of thermally converted waste [15]. Before the incineration process, energy is needed to evaporate the water.

The high water content, a ballast in thermal processes [16], is an advantage in biological waste conversion processes. This is because water is necessary for microorganisms to function appropriately and decompose the organic matter found in the waste being processed [17]. Depending on whether the process takes place under aerobic or anaerobic conditions, composting [18] and biogas production can occur using the anaerobic digestion process can occur [19,20]. With the right quality of collected substrates, it is possible to produce energy from both systems, especially in the anaerobic digestion process [21].

Biogas production from biodegradable waste, including biowaste, is one of the most popular methods of management [22]. Energy production through anaerobic decomposition is even a key direction in line with the idea of a circular economy [23]. The product of the process in question is biogas, which can be purified into biomethane [24]. In this case, the number of directions for its use increases. Another solution is to convert biogas using the cogeneration process. It provides electricity and heat [25]. Regardless of the biogas conversion methods, a second product is produced, which is the digestate [26]. The discussed post-process residue can be utilized in several ways, among which fertilizer use is predominant. The usefulness of digestate in agriculture has been described in many scientific papers [27,28].

An alternative to the anaerobic digestion process, a direction in the context of biological waste management methods, is composting [29]. Composting is a process that occurs under aerobic conditions, which is the main difference from the previous method discussed [30]. The product of the composting process is compost—an organic matter-rich fertilizer [31]. Due to its considerable diversity, biowaste can be used in composting [32]. It can play the roles of both raw material rich in macro- and micronutrients, e.g., kitchen waste, and be responsible for maintaining the appropriate structure in the composted mixture, e.g., branches from landscaping. Especially noteworthy is that in addition to obtaining compost, which is a valuable fertilizer, the heat generated by the process can be recovered [33].

A rational waste management process is one of the most critical elements of activities consistent with sustainable development and environmental protection. However, for the efficiency of the process to be as high as possible and the impact on the environment to be limited, particular emphasis should be placed on the increase in selective collection and the purity of the collected raw material. The changes in this sector should take place steadily and result in a systematic increase in indicators showing improvement.

This study aims to discuss the selective collection and management of biowaste from the municipal sector in Poland, along with identifying limiting factors. In addition, selected aspects of municipal waste production were discussed, along with identifying opportunities for its use. In preparing this paper, the author used scientific publications, industry reports, unpublished data, and information obtained at industry conferences or committees in which the author participated. The basis for writing the article was information obtained from scientific literature, legal acts, and reports, supplemented by the practical aspects obtained, among others, through interviews with the waste management industry workers.

## 2. Biowaste in Poland—Production and Properties

In 2020, Poland generated 13.117 million tons of municipal waste, recording a 2.9% increase in generation compared to the previous year. On a per capita basis, this means an increase in municipal waste generated from 332 kg in 2019 to 342 kg in 2020 [34]. However, it should be mentioned that the amount of municipal waste generated in Poland, per capita, is by far one of the lowest in Europe and the European Union.

The amount of municipal waste collected selectively is also increasing yearly, which is a positive phenomenon, not considering the reduced amount of waste generated. In 2005, selective collection accounted for only 3% of municipal waste (295,000 tons). In 2020, less than 5 million tons were collected selectively, accounting for 38% of the total municipal waste generated (Figure 1). It represents a 25% increase in selectively collected waste compared to the previous year [34].

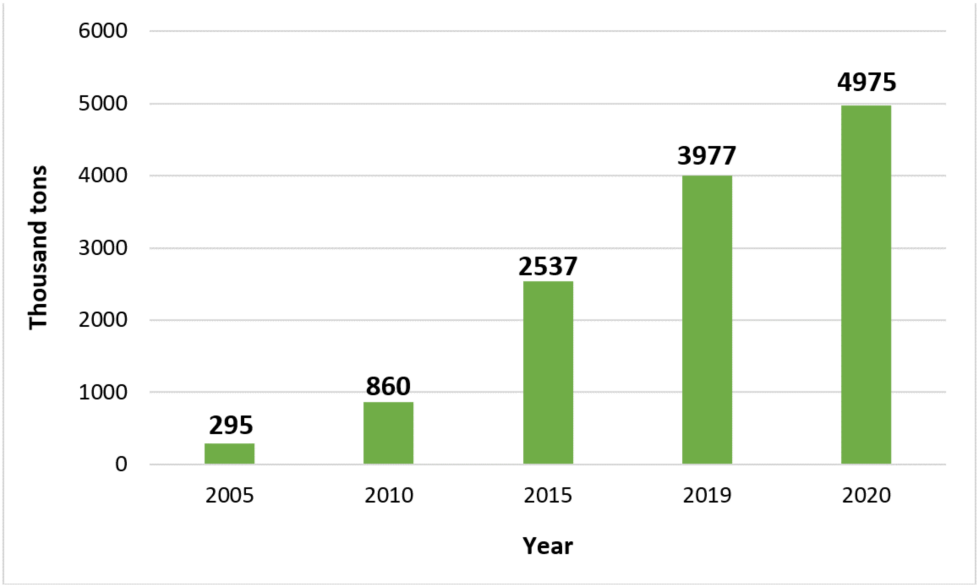


**Figure 1.** Municipal waste collected separately in Poland; own study based on [34].

In 2020, biodegradable waste accounted for the largest share of all separately collected waste [34]. Analyzing the data presented in Figure 2, it should be noted that the share of biodegradable separately collected municipal waste, in general, is steadily increasing. In 2010, it was 21.1%, and in 2020, it was 32.4% (Figure 2).

Rational management of biowaste is one of the most critical challenges for environmental protection and the aspirations for the circular economy principle [35,36]. The choice of technology and the number of facilities necessary for processing would directly result from the parameters describing the discussed group of waste. Primarily, mention should be made of the total amount of biowaste generated and, more importantly, collected in a given area. It determines the necessary capacity of the installation to manage it. In addition, the morphology of biowaste, dry mass, organic matter content, and accumulation rates, both daily, monthly, and annual, are essential parameters.

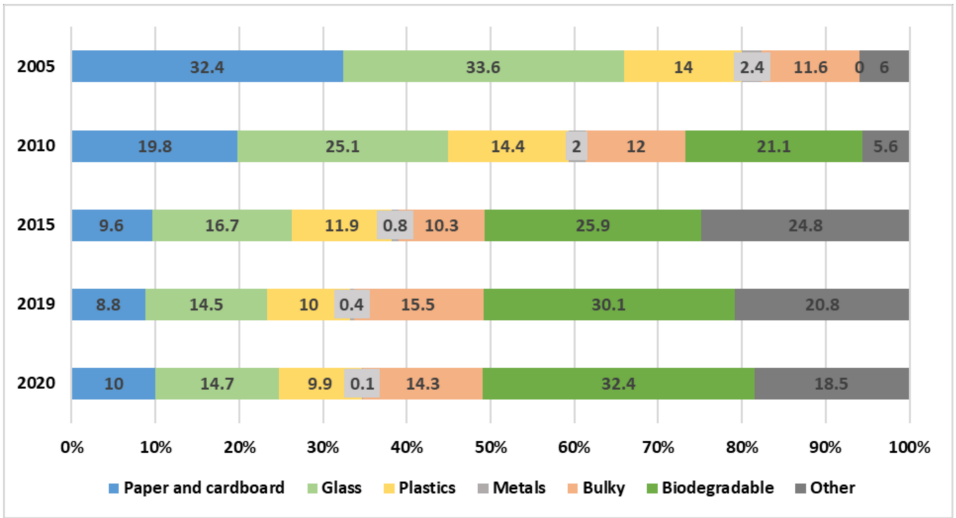


**Figure 2.** Structure of separately collected municipal waste by waste fraction; own study based on [34].

Figure 3 presents municipal biowaste generation per person and the share of biowaste in municipal waste generated by the country in 2017 [37]. For Poland, the share of biowaste in municipal waste generated is approximately 33%, which deviates from the average for the analyzed countries by only a few percent.

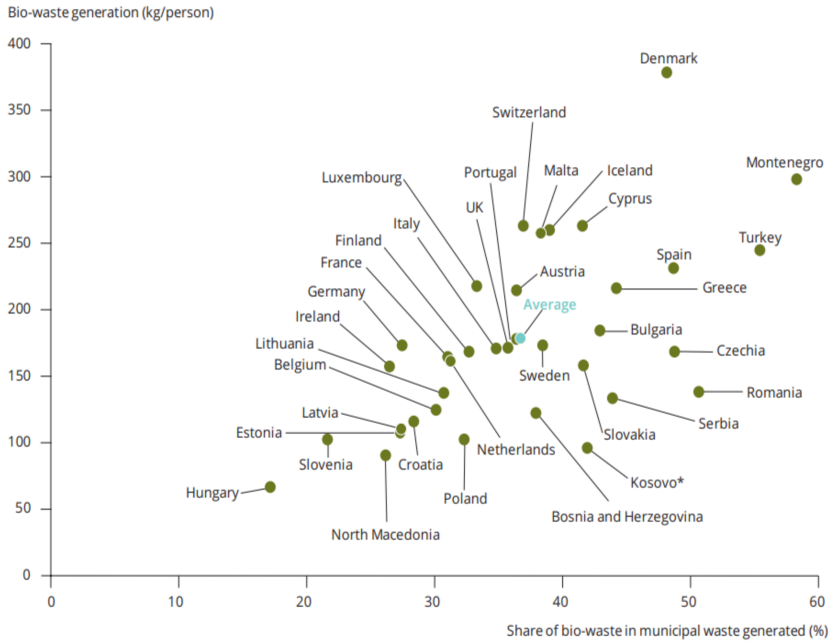


**Figure 3.** Municipal waste collected separately in selected European countries [37].

The amount of biowaste generated and collected in each country may differ significantly. It would have consequences in terms of the need for its management. According to the Regulation of the Minister of Climate and Environment of 10 May 2021, on the method of selective collection of selected waste fractions [6] in force in Poland, paper, glass, metals, plastics, multi-material packaging waste, and biowaste are collected selectively. The history of the selective collection of biowaste in Poland is relatively short, spanning only a few years. One of the main goals of such measures is to reduce the weight of the waste going to landfills. As a result, the level of selective collection of the waste in question would

increase. In addition, increasingly more waste should be managed through recycling or recovery processes.

To correctly manage the waste, it must first be classified appropriately. In Poland, this is performed using the so-called Waste Catalog defined by the Regulation of the Minister of Climate [11]. It classifies waste based on the source of its generation. Each waste is described by a code consisting of six digits, where the first two denote a group, the next two a subgroup, and the last two a type of waste. The catalog includes nearly 1000 types of waste classified into 20 groups. Biowaste from the municipal sector is classified primarily as biodegradable plant-origin kitchen waste (code 20 01 08) and biodegradable waste (including gardens and parks) described by code 20 02 01.

Biodegradable waste includes waste that undergoes aerobic or anaerobic decomposition with the participation of microorganisms [3]. According to the cited legal act, biowaste, on the other hand, is biodegradable waste from gardens and parks, food and kitchen waste from households, catering, mass catering establishments, and retail units, as well as comparable waste from establishments that produce or market food. The wastes classified in this group are listed in quite some detail so that there are generally no problems in classifying them. Biowaste from the municipal sector can be divided into kitchen waste (peelings, grounds, eggshells) and green spaces (plant residues, grass, leaves, branches). Despite this division, quite a few characteristics of most biowastes are common. Because of its characteristics, special attention should be given to them.

The first is susceptibility to decomposition [38], both in controlled and uncontrolled conditions. Discussing this characteristic, it is essential to mention the possibility of using biowaste in aerobic and anaerobic processes. It would make it possible to obtain compost, a suitably valuable fertilizer rich in organic matter [39], as well as biogas and digestate as fertilizer [40,41].

The following characteristic of biowaste is its relatively high water content. The broad range can vary from a few percent for dry biomass to even more than 90% for selected fruits and vegetables [42]. Water, along with the dry matter of substrates, often provides a suitable environment for the growth of microorganisms. The reason for this can be increased susceptibility to decomposition. Therefore, many activities related to biowaste should be undertaken quickly if they differ from other biodegradable waste, such as sawdust. An exception in the group of biowaste may be branches or shells, and a lower water content characterizes these waste.

Another characteristic of biowaste is its wide variety. As mentioned earlier, this group includes many types of degradable waste of all kinds [37]. Their diversity, quantity, and quality are subject to many fluctuations, those related to the place of production and the year's season. For example, the cleanliness of selectively collected biowaste in places of collective feedings, such as a canteen, would be different, unlike in multi-residential developments, where blocks of flats predominate. In the first site, a much more homogeneous and clean raw material can be expected. On the other hand, more grass is expected in warmer periods, while leaves play a significant role in autumn.

Biowaste is generated every day by all people worldwide. Therefore, its management should consider legal, social, technical, and economic aspects. Regardless of the management technology choice, the cost for each citizen should be as low as possible so as not to generate negative public opinion on the subject of waste management, which unfortunately often happens [43]. In addition, there are times when local government units have to subsidize the waste management system despite the relatively high premiums for waste collection and management. It should be mentioned that the quality of waste significantly affects the cost of waste management [44]. Thus, the key to achieving the desired results is to take care of the raw material's quality and choose the proper method of processing it [45].

## 3. Factors Limiting the Collection and Energy Use of Biowaste from the Municipal Sector

### 3.1. Social Factors

All waste-related activities should include rational and safe management and sustainable use of other natural resources. The Polish Act on Waste of 14 December 2012 [3], which implements the Waste Directive [46], introduces numerous regulations, including those concerning the five-stage waste hierarchy. Waste prevention, with disposal considered a last resort, is at the top.

Waste management is among the areas of environmental protection where many challenges remain [47]. In popular opinion, waste is seen as a problem. However, it should be noted that when used rationally, it becomes a valuable resource [48]. For this to happen, however, it must be collected and prepared for reuse, recycling, or recovery. The disposal of waste results in a nonrecoverable loss of resources, which is inconsistent with the goals of the circular economy. For this reason, domestic and international regulations are designed to address the best possible environmental outcomes from waste management [49].

Legal regulations in Poland require selectively collected biowaste from the society [6]. It involves separating another waste stream after glass, metal, plastic, and paper. Since the collection of biowaste from the municipal sector in Poland has a short history, many things must be changed, or rational solutions or optimizations must be chosen. One frequently discussed topic concerns waste management fees, which vary within the country. Among others, it is due to the types of installations and the distance to them from where the waste is generated.

Collecting waste at the source is a critical component of municipal waste management. The appropriate quality of selectively collected waste yields the most important economic, environmental, and social benefits. By segregating all waste, including biowaste, the public dramatically impacts other waste management.

All kinds of contamination present in the raw materials reduce their suitability for biological processing in biogas or composting plants. The costs of managing the waste in question also increase. In numerous instances, unwanted components in the waste stream are not captured and remain in the final product, which is compost or digestate. It reduces their value or even prohibits their disposal.

For some parts of society, the collection of the next fraction is already a cause of controversy. The first problems for the public have already arisen in connection with the need to buy additional containers to collect the waste group in question, both for the collection of waste inside the house and the larger, brown-colored container outside. There is controversy regarding household waste collection and storage and the expense involved. Over time, this obligation has become increasingly acceptable to many people.

In addition to the proper segregation of biowaste, following the requirements of the Regulation of the Minister of Climate and Environment of 10 May 2021 on the method of selective collection of selected waste fractions [6] and their collection into a brown-colored container, attention should be given to the quality of the collected substrates and the contaminants in them. The most common contaminant is plastic packaging, in which waste is removed. Therefore, particular promotional actions are taken, such as the action in the city of Poznan organized by the Poznan Agglomeration Waste Management Intermunicipal Association, "Biowaste on the loose." Despite information campaigns, food waste, including biowaste, is often directed to facilities in packages. The preparation of waste for further processes requires the separation of substrates rich in organic matter from packaging (mainly plastic). Therefore, equipment using a separation process is required. It should be mentioned that separated packaging waste is another stream to be managed. The second most important problem is dumping other waste into brown bins, such as meat waste, food waste, or mixed municipal waste.

### 3.2. Technical Factors

Biowaste is biodegradable under both aerobic and anaerobic conditions. This characteristic allows it to be used in composting [50] and anaerobic digestion [51]. Susceptibility to decomposition should be considered both an advantage and a disadvantage. The advantage is the broad spectrum of its use, while the disadvantage is the relatively short time it takes to manage it. In this context, transporting this waste to recycling plants comes into play.

Another problem may be the mismatch between the number and capacity of containers and the actual quantities of waste in question. It is also directly related to the frequency of waste collection, as these aspects affect each other. If the containers are overfilled, the biowaste would most often end up in containers for mixed municipal waste, making it impossible to separate and further manage it rationally.

Collecting biowaste from households is a fundamental measure for its rational management. Among the methods of waste collection, there are mainly all kinds of containers, bins, and bags. The bag collection system is most frequently introduced in single-family homes. Among the advantages is the lack of containers dedicated to collecting each fraction. However, this system has a disadvantage that is rarely mentioned. It is the production of the bag itself, which involves incurring a cost and producing another waste, which a bag becomes. The containers in which waste is collected should be closed to prevent animals from accessing it. It is also essential that the container has openings to allow air circulation.

Another solution to manage biowaste is composting. It can take place both in single-family homes and in multifamily developments. Managing waste on-site would reduce the costs associated with storage, transportation, and waste management. Therefore, it is a solution that should be considered and increasingly applied. Decomposition under aerobic conditions produces compost, which can be managed according to one's needs. It is worth mentioning that individual composting can be assisted by organisms such as earthworms [52].

Irregular waste receiving is one of the critical problems associated with waste management companies. In developed countries, this difficulty can arise, for example, due to changes in waste collection companies, e.g., after a new tender is awarded. It creates a logistical and aesthetic concern for plastic, glass, and paper waste. In this case, some waste may end up in mixed waste. The issue resulting from its decomposition under uncontrolled conditions can be more significant for mixed municipal and biodegradable waste.

### 3.3. Economic Factors

The cost of waste management by municipalities is steadily increasing. Among others, it is due to an increase in the cost of waste collection because fuel, electricity, and water fees are rising. The increase in the minimum wage and the adjustment of monitoring and fire protection systems are other expenses charged to waste processing plants. As a result, fees for residents are also increasing.

Society generally declares that it segregates waste properly. However, this is contradicted by the statistics on the amount of waste collected selectively. Based on the data presented in Figure 1, it should be concluded that there is still a large area for change. It should be unequivocally stated that education can help the most here. To convince the public to collect biowaste, systematic educational and promotional activities should be undertaken.

Contaminations found in biowaste are another problem directly affecting the cost of management. Among the contaminants found in the brown bin are plastics. Above all, this applies to commercial bags, sacks, and nets in which people discard waste. There is also confusion between black and brown containers; biowaste is thrown mixed with municipal waste. The waste can be cleaned, but this involves additional costs, and the effectiveness of the cleaning never reaches 100%. The amount of contaminants in the waste in question is often a few to several percent. All the collected contaminants constitute another waste, the contamination of which entails additional costs (Figure 4).

**Figure 4.** Contamination of biowaste collected selectively.

## 4. Opportunities for Change in the Biowaste Management Sector

The generation of municipal waste is an integral part of human life. Threats to the environment from its improper management primarily include the soil environment, water, air, or scenic qualities. However, if appropriate measures are taken to manage it, most potential risks can be reduced. In 2020, of the municipal waste collected and received in Poland, approximately 7.7 million tons were destined for recovery (59% of municipal waste generated), of which 3.5 million tons (27%) were for recycling, 2.7 million tons (20%) for thermal conversion with energy recovery, and 1.6 million tons (12%) for biological processing (composting or digestion).

A total of 5.4 million tons were diverted to disposal processes, of which 5.2 million tons (40% of municipal waste generated) were sent to landfills, and the remaining 0.2 million tons (1% of generation) were disposed of by thermal conversion without energy recovery [34]. Due to the efforts to achieve the highest possible amount of selectively collected waste, which the country is aiming for, it is expected that the amount of waste going to recycling will steadily increase while the amount of waste going to disposal processes will decrease.

The current law and the implementation of the waste management process by local government units have a crucial impact on the shape of the waste management system [53]. The goal of the European Union countries, including Poland, is to reduce the amount of waste generated and to direct as much of the generated waste to recycling and recovery processes as possible. These activities are to be in line with the concepts of a closed-loop economy.

In Poland, waste streams, such as paper and cardboard, glass, plastics, metals, and multi-material packaging are collected selectively. It is also possible to collect such waste as electronics, medicines, and bulky waste, but these must be delivered to particular collection points.

In addition to legal regulations and measures taken by the public, it is necessary to organize an appropriate waste collection system. Municipalities are waste owners according to the Law of 13 September 1996 on maintaining cleanliness and order in municipalities [54]. One of the goals of these regulations was to be the best possible waste management. Like other waste in the municipal waste stream, the amount of biowaste varies from municipality to municipality. The level of recycling itself also depends to a large extent on how the system of individual waste groups has been organized in the municipalities.

Data from recent years indicate that the amount of selectively collected biowaste in Poland is increasing. As a result, more facilities will be needed to manage this waste. For this process to take place with the most significant possible benefit to the environment, it is necessary to ensure consistent solutions involving legislation, company waste management, and public actions.

The issue of waste management, including biowaste, should be viewed as two essential aspects that affect each other. The first is the selective collection and disposal by people of properly collected waste. The second is its management, considering environmental but also economic factors. An essential aspect that can significantly correct the situation is waste collection logistics. In Poland, there is often a system of so-called "routes". It consists of the fact that a car picks up waste from specific locations in a constantly repeating cycle on fixed days. It does not consider how full the containers are. To some extent, this aspect can be regulated by the clear choice of the type and volume of containers, which would be adapted to household demand. However, interviews with industry representatives show that this is rare.

The collection time for biowaste should be as short as possible so that there is no uncontrolled decomposition. In practice, the waste in question is usually collected every 1–2 weeks, but there are cases when this period is extended even to a month. It involves its decomposition, which directly affects its further processing. Taking the correct action can avoid situations where a car picks up too infrequently overflowing waste containers. Modern systems and solutions to support the waste management system can help [55].

Public awareness of environmental topics is increasing every year. It is evidenced, among others, by the systematic increase in the amount of energy produced from renewable sources and the amount of selectively collected waste. Part of the public does not see the point in segregating waste, usually explaining it by lack of time or clear economic benefits manifested in reducing waste management fees. This is confirmed by the increase in waste management fees in most Polish municipalities despite the systematic increase in the amount of selectively collected waste.

People know that less waste production and better waste management positively impact the environment. However, as unpublished data obtained as part of research at the Poznań University of Life Sciences suggest, many people do not see a correlation between reduced waste management fees and increased levels of separate collection and recovery. Numerous factors are responsible for this, including an increase in the cost of waste management, an increase in the price of transportation services, or even an increase in the country's minimum salary. However, it should be emphasized that proper waste segregation and management make it possible to reduce waste management fees. Recycling, which includes both anaerobic digestion and composting, makes it possible to reduce the amount of waste sent to landfill or incineration, the disposal processes at the very end of the waste hierarchy [56].

The benefits to society of proper waste management include economic and environmental aspects. The key to increasing the efficiency of biowaste management is its selective collection at the source. Collecting directly into small containers or paper bags among household biowaste collection systems should play a key role. Avoiding throwing biowaste into mixed waste or disposing of it in plastic bags makes it difficult or completely impossible to use it rationally.

Methods based on the Life Cycle Assessment are increasingly used in scientific research. According to Mishra et al. [57], the Life Cycle Assessment is an important element to improve the sustainability of biowaste management systems. The main aim of the research by Guillaume et al. [58] was to assess current biowaste management strategies in Prague via LCA to identify key parameters and suggest improvements at a municipal level. As the authors emphasize, using both composting and anaerobic digestion is recommended to meet EU targets.

## 5. Conclusions

Rational management of biowaste with unique properties is not an easy or inexpensive task. It is due to, among others, legal, technical, technological, or economic aspects. On the other hand, biowaste can be a valuable raw material for producing biofuels, fertilizers, and many other products. Hence, it is necessary to carry out activities at the national, regional, local, and even household levels that would reduce its nuisance to the environment and human health and provide opportunities for its appropriate disposal. It would make it possible to obtain better raw materials to produce additional products following the circular economy principle. Such action would improve the balance of operation of waste processing facilities and reduce the resulting costs for residents.

Biowaste is a significant group among all waste fractions. According to various estimates, its amount in the total waste stream can be up to 50%. Although selective collection is costly and often problematic, it is essential to the waste management system. However, statistics for many countries, including Poland, indicate that the amount of selectively collected biowaste is only a small part of the estimated production. On the positive side, however, there is an apparent systematic increase in selectively collected waste (Figure 1).

Waste management challenges local governments, waste collection and management companies, and residents. However, thoughtful action must be taken to achieve the desired effect. Satisfactory results in the waste management sector can only come from coordinated action. This is because the waste management system is a dependent whole. Negligence occurring at each stage, starting with segregation, would result in a negative impact at a later stage or stages. In addition, it should be mentioned that the purity of the raw material or waste determines its economic value. Therefore, the most significant possible benefits for more homogeneous and uncontaminated waste can be obtained. A crucial issue is the public's systematic education on waste management and environmental protection in general. These activities should bring tangible results.

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