

ANNA JANDA (ORCID: 0000-0002-0553-9609)<sup>1</sup>

WERONIKA URBAŃSKA (ORCID: 0000-0002-6523-7629)<sup>1</sup>

## WASTE MANAGEMENT COSTS. A CASE-BASED STUDY ON SELECTED POLISH CITIES

This article attempts to find the strongest factors that impact waste management system costs. Case-based studies in three selected voivodeship Polish cities, Opole, Gdańsk, and Cracow found waste collection and transport, processing, and system management to be the dominant cost factors. The price of fuel, electricity and the rates of wages indirectly decide the determined management costs in the above-mentioned categories. The increase in waste management costs on a national scale observed in recent years is mainly from actions taken by companies to meet increasingly restrictive legal requirements. For example, the allowed time for waste storage has been shortened and the amount of environmental fees paid for waste landfilling has been increased. In addition, the obligation to watch the temporary storage and landfill as well as the implementation of fire protection rules. In the cities analyzed, the increase in waste management operating costs between 2017 and 2021 ranged from 41.3% for Gdańsk to 63.5% for Opole.

### 1. FORMAL REGULATIONS OF MUNICIPAL WASTE MANAGEMENT IN POLAND

The management of various waste streams is the basis for modern environmental protection systems and the prevention of climate change. All activities undertaken in this area are regulated by law. In Poland, the most important legal act in the field of waste management is the Act of December 14, 2012, on waste (Journal of Laws 2022, items 699, 1250, 1726). This act defines the waste concept and shows the waste management hierarchy. According to the hierarchy, waste prevention is the most desirable action. If waste is generated, its processing should follow the principles of a circular

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<sup>1</sup>Wrocław University of Science and Technology, Faculty of Environmental Engineering, Plac Grunwaldzki 13, 50-377 Wrocław, Poland, corresponding author A. Janda, email address: [anna.janda@pwr.edu.pl](mailto:anna.janda@pwr.edu.pl)

economy, striving to minimize the use of raw materials and waste production [1]. Under the Waste Act, waste management plans are developed at the national, municipal, district, and municipal levels, specifying the scope of activities for sustainable waste management. The plans also define the goals that should be achieved in the perspective period [2].

Following the Act of September 13, 1996, on maintaining cleanliness and order in municipalities (Journal of Laws 2022, item 1297), the creation and operation of waste management systems in the commune authorities' responsibility. The commune tasks hold the organization of the waste collection system and its coverage of all properties on which waste is generated, including inhabited and uninhabited. In addition, municipalities must build, support and run waste treatment installations. Municipalities are also subject to the obligation of annual reporting on waste management activities.

Under the Act on Maintaining cleanliness, municipal waste should be collected selectively. The separate collection system should cover at least fractions of paper and cardboard, glass, biowaste and plastics, metals, and multi-material packaging waste. In addition, communes must create points for separate municipal waste (PSWC). The commune council sets up detailed regulations to maintain cleanliness and order, including the principles for waste collection, the frequency of its collection, and the rules of operation of the PSWC.

Waste producers pay a waste management fee. The revenues of the commune's budget cover the costs of operating the integrated municipal waste management system. The municipal council decides about the upper rates of fees paid by property owners for waste management services, with higher rates being applied if municipal waste is not collected selectively. The rates can vary depending on the population density in each area and the distance from the municipal waste treatment site. The factors that determine the amount of the fee for municipal waste management are the number of residents living in the commune, the amount of municipal waste generated in the commune, the costs of the municipal waste management system, and the seasonality of municipal waste generation. For inhabited properties, the amount of the municipal waste management fee is the product of multiplication: (i) the number of residents of a given property, (ii) the amount of water consumed from a given property, (iii) or the usable floor space of a dwelling, and the fee rate determined by the commune council. It is possible to use a combination of different criteria. For uninhabited properties, the municipal waste management fee is the product of the declared number of containers or bags, the number of emptying them, and the agreed rate of the management fee. The provisions of the act on keeping cleanliness before the amendment (September 2021) suggested the need for self-balancing of waste management systems. The latest records say that subsidies to the systems are possible from external sources, i.e., other than the fee charged to property owners.

## 2. FACTORS AFFECTING THE COSTS OF MUNICIPAL WASTE MANAGEMENT

The costs of waste management are shaped by activities directly related to their processing, as well as by external factors. The costs of waste management include waste collection, transport, and processing, system management, investments, and education, and added activities. External factors that have an indirect impact on waste management costs include the political, social, and economic situation in the country and the world.

The entire waste management process begins with the collection of waste from the place where it is generated. The size of the waste stream, the frequency of collection, the size of the area (city/municipality) covered by a given system and the current fuel price have the greatest impact on the costs of waste collection and transport. The frequency of waste collection is related mainly to the amount of waste generated, the structure of the selective waste collection, and the properties of individual material fractions, and is determined by municipal regulations. Waste collection and transport require the maintenance of a suitable fleet of trucks. In addition, the commune can also distribute more funds to equip the property with containers and/or bags to collect waste and to remove and transport waste from places not intended for storage (from the so-called wild dumps) [3].

The next stage of waste management is its processing. This should be understood as the processing of all waste streams that go to waste management plants, i.e., the stream of separately collected waste (including bulky waste and biowaste), and mixed waste. For mechanical-biological waste treatment plants (MBP), the costs of this stage include sorting, stabilization (aerobic or anaerobic) of waste with a high content of biodegradable fraction, production of substitute fuel and waste storage. For thermal waste treatment (THR) plants, the costs include waste unloading and transporting, operation of a thermal installation with a cogeneration system, operation of an exhaust gas treatment installation, valorization and storage of slag, and waste storage. Waste treatment costs also include measures related to the maintenance, expansion and modernization of the existing infrastructure. Landfilling requires the payment of the environmental fee [4]. Energy and employee costs are also important. MBP plants show a high demand for energy resulting from powering devices in the mechanical part and maintaining the proper conditions for conducting processes in the biological part. Supporting waste management processes requires the provision of a suitable number of employees, including sorters and machine operators. Waste treatment costs also have possible penalties imposed on the enterprise for failure to comply with requirements regarding the levels of waste preparation for reuse and recycling.

Another element generating the costs of waste management is the construction and maintenance of points for selective waste collection (PSWC). At these points, residents can deposit waste that is not directly picked up at the place where it is generated. The PSWC should be created in a way that allows easy access for all residents. The transport

of waste to PSWC is the responsibility of the resident, which is a great difficulty for people who do not have a means of transport. Some municipalities, to meet the needs of residents, introduce mobile PSWC in the form of specially adapted vehicles that appear periodically at specific places and collect waste such as used electronic equipment, medicines or chemicals. Such solutions are associated with an increase in the waste collection and transport costs. In addition, according to the provisions of the law on keeping cleanliness, the commune may also establish product repair and reuse [3]. Such activities allow the implementation of waste hierarchy principles. Establishing and supporting such facilities generates added costs of running a waste management system.

The proper functioning of the waste processing system requires proper management. This group of costs includes employee financing (salaries, benefits, staff training) and the charges of preparing reports, expert opinions, studies, analyzes, etc.

Investments are another part of the waste management cost structure. The tightening legal requirements about the levels of recycling and preparation of waste for reuse, as well as the landfill waste mass reduction, mean that waste management plants are forced to constantly implement new and efficient waste sorting systems and automate existing technological lines. In October 2020, as part of the work on the amendment to the national waste management plan, the Ministry of Climate and the Environment published a draft assessment of the investment gap in the field of waste prevention and management [5]. The document shows that the improvement of the national waste management system by 2034 requires the following:

- construction of 814 new PSWC with repair points and modernization of 570 existing facilities (PLN 4.40 billion),
- construction of about 200 sorting plants of separately collected waste with a capacity of 10 000 t/year, change and/or retrofitting of some existing installations (PLN 5.88 billion),
- construction of a biowaste fermentation installation with a total capacity of 1 260 000 t/year, with the provision of an aerobic second stabilization stage (PLN 3.44 billion),
- construction of a composting plant with a total capacity of 870 000 t/year and retrofitting of some existing installations (PLN 1.82 billion),
- construction and retrofitting of installations for the recycling of glass cullet, paper, metals, plastics, and multi-material waste (more than PLN 9 billion).

The total investment costs planned for the years 2020–2028 and 2029–2034 amount to PLN 18.7 and 5.8 billion, respectively. A significant part of the funds is to be covered by the EU under the New Financial Perspective of the EU 2021–2027. The remaining charges will be covered by state funds and the own resources of waste management sector enterprises. In the coming years, investments in the waste management sector will also be related to the decarbonization of transport, which is one of the main factors creating the costs of waste collection and transportation.

The last element that creates the costs of waste management is information and educational activities. These activities include raising awareness in the field of proper municipal waste management, the principles of selective waste collection, the implementation of a circular economy, and environmental education. Educational and information activities are conducted through lectures, seminars, meetings, and competitions.

In addition to direct activities related to waste management, there are also external factors that indirectly affect the operating costs of the entire system. That includes the economic and political situation in the country and the world. One of those factors is the outbreak of the COVID-19 pandemic, which in recent years has had a significant impact on the economy and daily life of society. Regarding waste management, the pandemic outbreak caused the implementation of special procedures for waste handling and the use of personal protective equipment by employees involved in collection, transport, and manual waste sorting. The chaos in the first pandemic period was also visible in the quality of the separate collection when people didn't know how to handle waste during isolation or home quarantine. Limiting social life and switching to home office work resulted in changes in municipal waste generated in households and outside of them [6]. As a result of online shopping and the development of the e-commerce industry, the number of cardboard and plastic packaging wastes appearing in the municipal waste stream increased [7]. Another factor influencing the waste management sector is sudden changes in the size of the waste stream caused, for example, by migrations. The best example is the sudden influx of people from Ukraine seen in Poland since February 2022. Depending on the method of determination of waste fees adopted by the commune, this situation can cause financial arrears for waste management companies in the current or next year [8]. In practice, the above-described factors force the introduction of changes to the waste collection system and the intensification of the sorting process.

In recent months, significant growth has been observed in electricity prices, mainly due to the increasing fees for CO<sub>2</sub> emissions allowances [9]. Waste management plants require continuous power to the sorting line devices and other technological devices. The expansion in energy rates influences waste processing costs. With fuel prices, the situation is similar: Fuel costs shape the prices of waste transport and processing, requiring the use of machines and vehicles.

### 3. ANALYSIS OF THE MUNICIPAL WASTE MANAGEMENT SYSTEM COSTS FOR SELECTED POLISH CITIES IN 2017–2021

Currently, there is no universal method to determine the cost structure of the waste management system. Each commune, as part of the mandatory reporting on its activities, individually classifies the costs of its system in the categories described in section 2 [10]. For example, the city of Gdańsk shows two main types of costs – investment and current, where the next four categories of current costs are mentioned, that is, collection and

transport of waste, processing, system management, and education [11]. The city of Opole classifies costs into five categories, where, compared to Gdańsk, the fifth category is the maintenance of stationary and mobile PSWC [13]. In its annual reports, the capital city of Warsaw includes four main categories of costs, within which it supplies the participation of individual components in each category. Costs are classified in a much more extensive way by the City of Cracow, where within the five main categories, a total of several cost subcategories are distinguished [14]. For comparison, the city of Wrocław until 2020, supplied only the general costs of waste management for individual city districts. In 2021, the costs related to waste management were classified into four groups, specifying the costs of collection and management of mixed waste, collection and management of separately collected waste, collection and management of waste in PSWC, and disposal of wild landfills [15].

The following part of the article analyses the costs of waste management for three selected voivodeship cities in Poland: Opole, Gdańsk, and Cracow. Detailed data on cities are presented in Table 1 [16, 17]. Gdańsk and Opole were analyzed together as cities that implement waste processing using MBP technology. Due to the installation of THR, the waste management in Cracow was analyzed separately.

Table 1

Characteristics of the cities covered by the analysis

City	Opole	Gdańsk	Cracow
Voivodeship	Opole	Pomeranian	Lesser Poland
Population (person)	130 000	490 000	800 000
Land area, km <sup>2</sup>	149	262	327
Population density, person/km <sup>2</sup>	856.8	1796.6	2388.9
Waste processing technology	MBP	MBP	MBP + THR

MBP – mechanical-biological technologies, THR – thermal processing.

### 3.1. WASTE MANAGEMENT COSTS FOR GDAŃSK AND OPOLE

Opole and Gdańsk carry out waste treatment processes in MBP plants in oxygen technologies. Calculated per capita, the mass of municipal waste collected in Gdańsk in 2020 and 2021 was 421 and 443 kg, respectively (excluding construction and demolition waste). More than 50% of the waste mass consisted of unsorted waste with the code 20 03 01. Over 95% of the waste mass was collected directly from the residents. The remaining waste stream was collected at PSWC, during occasional waste collection, and at points of raw material purchases points. The total mass of municipal waste collected in Gdańsk in 2017 and 2021 was 189.3 and 206.7 thousand tons, respectively. In Opole, the waste accumulation indicators per capita were higher than in those in Gdańsk and in the years 2020–2021, they amounted to 536 and 561 kg, respectively. Mixed waste had the highest share in the total municipal waste stream. 82% of the waste was collected

directly from property owners, 12% was collected by business entities, and 5% of the waste was transferred to the PSWC. The total mass of municipal waste collected in Opole in 2017 and 2021 was 48.9 and 57.3 thousand tons, respectively.

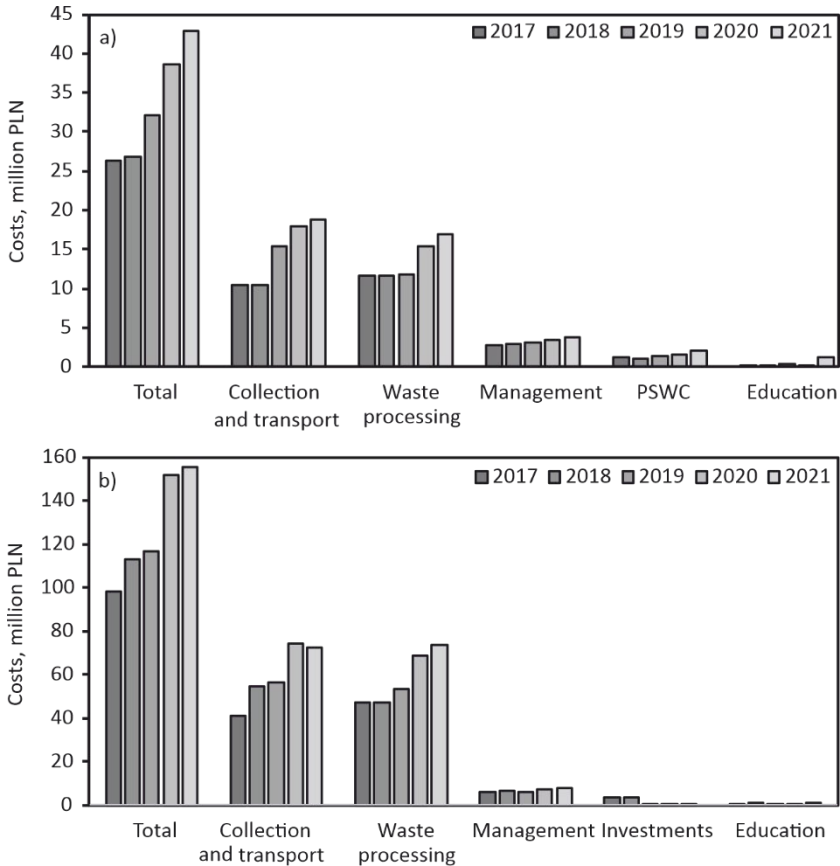


Fig. 1. Analysis of waste management costs in 2017–2021 in Opole (a) and Gdańsk (b) [11, 12]

The rate of waste fee in Gdańsk is determined depending on the area of the property, while in Opole, it depends on the number of people living on the property. In both cities, the rates are higher for declarations of waste collection in a nonselective way. In Opole, until 2019, the monthly fee for waste collected selectively and non-selective way per capita was PLN 13 and PLN 20, respectively. In 2020, the fee increased to PLN 19 and PLN 38, respectively. From 2021, the monthly fee for waste collection is PLN 28 and PLN 56 [12]. In Gdańsk, up to 2020, the fee was 0.44 and 0.88 PLN/m<sup>2</sup>, respectively, for waste collected selectively and non-selectively (for properties with an area of up to 110 m<sup>2</sup>). From 2020, the fee amount expanded to 0.88 and 1.76 PLN/m<sup>2</sup> [11]. Both cities

apply discounts to residents in the case of biowaste composting declarations at PLN 1.50 per capita or PLN 0.03 per m<sup>2</sup>.

Figure 1 presents a cost analysis of the waste management system in Opole and Gdańsk in the years 2017–2021. Data compilation is based on mandatory annual waste management activities reports [11, 12]. The total cost of waste management in Opole and Gdańsk in 2021 was PLN 42.9 million and PLN 155.4 million, respectively. Both cities have seen a significant increase in the total cost of their waste management system over the past five years. For Opole, the increase in costs in 2021 compared to 2020 and 2017 was 11.2 and 63.5%, respectively. For Gdańsk, these values were 2.2 and 58.1%, respectively. In both cities, the costs of waste processing, as well as collection and transport, had the highest share in the cost structure. These components of the system in Gdańsk accounted for 47.4 and 46.6%, respectively, and in Opole 39.5 and 43.8% of the total costs incurred for waste management. In 2019, the charges related to the transport of waste in Opole increased by 46.4% compared to 2018, and in 2020 by another 16.8% compared to 2019. The situation in Gdańsk was similar, where the growth in the cost of waste for 2020 was 31.5% compared to the previous year. Within five years, the costs of transporting waste in Opole and Gdańsk increased by 79.0 and 75.3%, respectively. In the analyzed period, the costs of waste processing increased by 46.2% in Opole and 56.2% in Gdańsk, respectively. In 2020, the most significant expansion in waste processing costs was recorded compared to the previous year, i.e., 31.1% in Opole, and 29.0% in Gdańsk. The increase is also visible in the growth in the prices of waste collection in waste management plants. Detailed data are summarized in Table 2.

Table 2

Costs of managing selected municipal waste fractions in Gdańsk in 2017–2021 [PLN/t]

Type of waste	Year				
	2017	2018	2019	2020	2021
Unsorted municipal waste	341	350	395	590	540
Biodegradable waste	256	175	163	203	245
Biodegradable kitchen waste	–	235	214	202	167
Bulky waste	216	294	365	925	626

Table 2 shows the average costs of processing the selected waste for the city of Gdańsk. Based on the presented data, it can be noted that over the years 2017–2021 the charges of mixed and bulky waste management increased significantly – in 2021 by 72.3 and 189.8%, respectively, compared to 2017. Data from the ministerial report, including an analysis of collection prices in the years 2019–2021 for 28 national waste treatment installations, confirm the expansion of the mixed, bulky, and biodegradable waste by 36, 78, and 40%, respectively [10].

During the period 2017–2021, the costs related to system management also increased significantly (Fig. 1). In 2021, the management costs for Opole amounted to



PLN 3.9 million and for Gdańsk – PLN 7.7 million, which was an increase of 39.2 and 31.4%, respectively, compared to 2017. In Opole, the share of management charges ranged from 8.8 to 11.1% of total costs and was almost twice as high as in Gdansk. During the years 2020–2021, Opole recorded an increase in fees associated with the running PSWC by 30.8%. It was caused by investments related to the launch of a second stationary point in the city in October 2021. Gdansk is currently implementing investment processes for the construction of seven PSWCs. Two points are to be commissioned in 2022 and 2023. The next four investments are at the stage of selecting contractors and legal and location arrangements. Furthermore, investment needs have been identified for the following years, including, among others, the construction of a bio-waste fermentation and leachate pretreatment plant, expansion of sorting and composting plants, and installation of a photovoltaic system. the above activities will cause an increase in investment costs.

The costs of educational activities account for a small portion of the operation of waste management systems. however, in the years 2017–2021 in Opole and Gdańsk, expenditure on educational activities increased almost two and tenfold, respectively. in the analysis of educational costs in 2021, Opole lists, among others construction of a re-user for the exchange of items between residents, the signing of a cooperation agreement with the school board and conducting training on the implementation of circular economy principles. seven educational projects were also carried out in Gdańsk.

Both cities recorded a positive financial balance in the operation of their waste management systems. for Opole, the surplus amounted to more than PLN 2.9 million and for Gdańsk, PLN 21.7 million. as shown in the annual report [11], in Gdańsk, positive financial balance sheets have been recorded since 2018. In addition, the COVID-19 pandemic caused a delay in the implementation of investments related to the construction of PSWC, which resulted in the unused funds allocated for this purpose.

### 3.2. WASTE MANAGEMENT COSTS FOR CRACOW

In Cracow, there are 3 plants carrying out MBP processes and one THR processing plant. The waste accumulation rate in 2020 and 2021 was 495 and 488 kg/person, respectively. In 2021, more than 95% of the generated waste was collected directly from property owners. Almost 50% of the municipal waste stream was mixed waste and was sent for processing in the MBP (53.2%) and THR (46.8%) installations. Additionally, the THR installation processed the stream of waste staying after mechanical treatment of municipal waste, code 19 12 12, with a weight of 143 156 tons [14]. The total mass of municipal waste produced in 2017 and 2021 was, respectively, 340.6 and 360.2 thousand tons.

The rate for waste management in Cracow is calculated based on the number of inhabitants making up the household, depending on the declared method of waste collection. From 2020, the rate is PLN 23 or PLN 46/person, respectively, for selective and

nonselective waste collection. For properties declaring biowaste composting and for large families, allowances are granted for PLN 4, and PLN 4.60/person, respectively. Until 2020, the rate additionally depended on the number of members living in the household and the type of building. Detailed data on fee rates are presented in Table 3. In 2020, there was a significant increase in fees for waste management paid by residents. For example, for a family of four that collects waste selectively, the waste management increased by PLN 36 or PLN 42, respectively, for single- and multi-family housing.

Table 3

Fee for waste management in Cracow in 2017–2020

Type of waste collection	Household size (person)						
	1	2	3	4	5	6	7 and more
Single-family housing							
Selective	26	36	46	56	63	66	69
Non-selective	39	54	69	84	94	99	103
Multi-family housing							
Selective	15	29	41	50	56	59	62
Non-selective	22	41	60	73	82	86	89

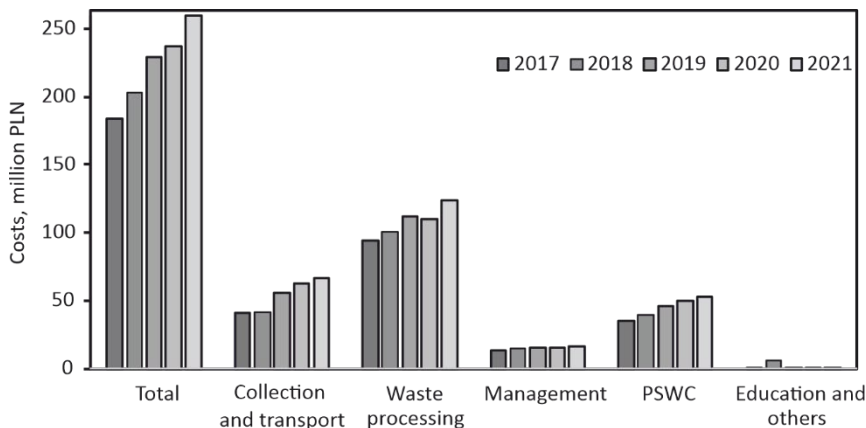


Fig. 2. Analysis of waste management costs in Cracow in 2017–2021 [14]

Figure 2 presents the costs of running the waste management system in Cracow in 2017–2022. To standardize the presentation of the data analyzed in Chapters 3.1 and 3.2, the costs are grouped into five main categories. Annual reports on waste management in Cracow [14] distinguish more subcategories within the collection and transport of waste, its treatment, and maintenance of PSWC. The detailed cost structure for the years 2020–2021 is presented in Table 4.

Table 4

Detailed costs of waste management in individual subcategories [14] [PLN million]

No.	Main category	Subcategory	Year				
			2017	2018	2019	2020	2021
1	collection and transport	MW <sup>a</sup>	40.7	41.9	49.9	40.1	43.0
2		SC <sup>b</sup>				13.6	15.0
3		kitchen and bio				6.1	9.0
Total in the category			40.7	41.9	56.0	62.6	66.9
4	processing	MW in MBP	38.1	40.2	40.8	40.8	41.4
5		MW in THR	26.2	28.6	26.3	19.7	21.9
6		SC sorting	17.7	18.3	19.3	19.2	21.3
7		composting	4.0	4.9	5.1	5.9	11.8
8		electronics and bulky	4.7	6.1	7.1	8.0	12.3
9		processing at external facilities	–	–	10.6	13.6	12.9
10		confectioning	3.0	2.9	2.6	2.6	2.1
Total in the category			93.7	101.0	111.8	109.8	123.6
11	PSWC creating and maintenance	PSWC	6.8	6.9	6.8	5.3	4.4
12		bulky waste <sup>c</sup>	7.8	8.2	10.4	12.2	12.8
13		green waste <sup>c</sup>	13.9	17.3	19.9	23.1	25.0
14		glass waste <sup>c</sup>	6.5	7.0	8.0	8.7	10.1
15		medicine <sup>c</sup>	0.1	0.1	0.3	0.7	0.8
Total in the category			35.1	39.5	45.4	50.0	53.0
16	management	employees	9.1	8.3	15.0	15.2	16.0
17		administration	4.4	6.4			
Total in the category			13.5	14.7	15.0	15.2	16.0

<sup>a</sup>MW – mixed waste.<sup>b</sup>SC – selectively collected waste.<sup>c</sup>Bulky, green, glass waste and medicine – with collecting and transport.

As shown in Figure 2, in the period analyzed, the costs of running the waste management system in Cracow have been systematically increased. The total cost of waste management in 2021 was almost PLN 260 million, which was an increase of 41.3% compared to 2017 and 9.3% compared to the previous year. The largest share of the cost had waste processing, which in the analyzed period represented 46.1–51.1% of the total structure. The growth in waste processing in 2021 compared to 2017 was 41.3%. Another important factor shaping the costs of the system, as in Opole and Gdansk, were the costs for waste collection and transport. In 2021, these costs amounted to PLN 66.9 million and accounted for 25.8% of total costs. The share of waste transport costs in Cracow is much lower than in Opole and Gdansk, where in 2021 it accounted for 46.6 and 43.8%, respectively. This is because in its reports Cracow includes the costs of collection and transport of selected groups of waste in the costs of PSWC operation (Table 4). For this reason, the costs of running PSWC are, in turn, much higher than in

Opole and account for about 20% of the total structure. In the period analyzed, the costs of collecting and transporting waste and running the PSWC recorded the most significant increase compared to 2017, totalling 64.4% and 51.9%, respectively.

The data presented in Table 4 allow us to show which activities of the waste management sector in Cracow contributed to the expansion of the operating costs of the entire system. Among the costs of waste treatment, it can be seen that a constant increase in costs over the years 2017–2020 for processes related to the sorting of separately collected waste and the processing of mixed waste in MBP installations. At the same time, in the years 2020–2021, a decrease in costs related to the treatment of thermal waste was observed. 81.4 and 87.6 thousand tons of mixed waste were thermally processed in 2021 and 2020 (for comparison, in 2018 it was 122.4 thousand tons) [14]. Over the years analyzed, the costs of composting organic waste, including green and another biowaste, and the costs of processing bulky waste almost doubled. There was also an increase in charges related to the receipt of the above-mentioned fractions at selective collection points.

## 4. DISCUSSION

In recent years, in the three cities – Opole, Gdansk, and Cracow, a systematic increase in the operating costs of waste management systems have been noted. This situation was reflected in the expansion in fees for waste management paid by waste producers. The factors with the highest share in the cost structure and, at the same time, with the highest increase in the analyzed period were the costs of transport, waste processing, and system management. The following discussion presents the most likely reasons for the observed cost growth.

### 4.1. TRANSPORT

In the years 2017–2022, an obligation to selectively collect biodegradable waste was introduced. Analysis of the Cracow waste management structure [14] showed that in 2020 the costs of collecting this waste material fraction of waste were more than 47% higher than in the previous year. Apart from the measures resulting from the applicable national legislation, the cost of waste transport is primarily decided by the current fuel prices. Figure 3 shows the changes in the wholesale cost of fuel purchase in the period from 2017 to 2022.

In 2017, prices of all types of fuel were below PLN 4000/m<sup>3</sup>, while in 2018–2019 a relatively slight increase in prices was recorded (Fig. 3). Due to the continued decrease in crude oil values on global stock exchanges, in 2020 the cost of wholesale fuel purchase fell to approximately PLN 3500/m<sup>3</sup>. Since 2020, the prices of Pb 95 and Pb 98 gasoline and diesel oil have grown dynamically. Currently, the most expensive fuel offered by PKN Orlen company is Arctic 2 diesel oil, which is adapted for use in extremely

low temperatures (ca. PLN 6400/m<sup>3</sup>). The high price is also achieved with Pb 98 gasoline – almost PLN 6300/m<sup>3</sup>. The wholesale price of Ekodiesel is currently almost PLN 6200/m<sup>3</sup>, and Pb 95 gasoline is over PLN 6000/m<sup>3</sup>. Since 2020, the rates for 1 m<sup>3</sup> of fuel have increased by an average of PLN 2600. The fuel market is sensitive to any economic change, as shown by the data for the period from 2020 to 2022. From the beginning of 2022, there was a constant expansion in the fuel market prices, however, in the period July–September 2022, a significant decrease could be observed in charges on the Polish fuel market – on average by ca. PLN 1000/m<sup>3</sup>. This shows that the estimation of the costs related to the transport of waste can be affected by a large error, resulting in underestimation or surplus in the budgets of the waste management sector.

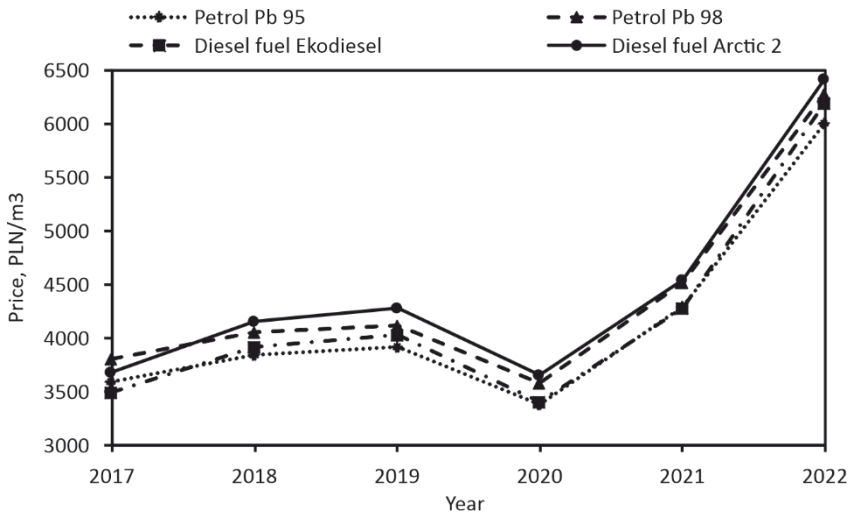


Fig. 3. Wholesale fuel prices in 2017–2022 (data until 30.09.2022) [18]

In addition to fuel prices, the cost of transport is also related to the price of AdBlue, which is necessary for diesel vehicles to neutralize harmful substances to the environment. More specifically, AdBlue is a 32.5% aqueous urea solution used in the automotive sector as a reducer of environmentally harmful nitrogen oxides. The necessity to apply this solution results from the emission reduction standards introduced in 2014. The price of this supplement in June 2021 was approximately PLN 2/dm<sup>3</sup>, and in November 2021 – PLN 3.49/dm<sup>3</sup> [19]. Currently, the cost of purchasing AdBlue is on average PLN 7–10/dm<sup>3</sup>. The increase in its prices is a consequence of the growth in the rates of natural gas, from which ammonia is obtained on an industrial scale, an intermediate used in AdBlue production. The persistence of the crisis reveals problems with fluid availability, which also affects its price. Furthermore, it is shown that the expansion in the cost of purchasing AdBlue is particularly noticeable in the case of truck owners (which also applies to the waste management industry due to the use of this type

of vehicle for waste collection), which consume a lot of solution due to much higher mileage than passenger vehicles. It can therefore be concluded that recently the annual expenses for one truck increased by up to several thousand PLN.

#### 4.2. WASTE PROCESSING

An important factor that influenced the increase in waste processing costs was undoubtedly the change in the legal regulations regarding waste storage and landfilling. The necessity to reduce the mass of landfilled waste resulted in an abrupt expansion in the fee for using the environment. The amount of this fee is decided annually in the Notice of the Minister of the Environment. In 2017, the fee for landfilling waste after oxygen decomposition (waste code 19 05 99) was PLN 24.15/t. In 2018, the amount of the fee was increased to PLN 140/t, in 2019 to PLN 170/t, and in 2020 to PLN 270/t for landfilled waste [4]. In the regulation of the Council of Ministers of 6 March 2017 amending the regulation on environmental fees, it was established that when the stabilizer with code 19 05 99 meets the requirements for respiratory activity ( $AT4 < 10 \text{ mg O}_2/\text{g d.m.}$ ), the loss on ignition ( $< 35\%$ ) and organic carbon content ( $< 20\% \text{ d.m.}$ ), the fee can be reduced to 1/4 of the amount. Confirmation of the above-mentioned fulfillments requires monthly laboratory testing of a stabilized sample, which increases the cost of waste treatment. Enterprises are trying to reduce the weight of landfilled waste – for example, in 2021 Cracow reduced the weight of landfilled waste by over 30% compared to 2018. In addition, in accordance with the provisions introduced in the 2018 amendment to the Act on waste, in response to a wave of fires at municipal waste storage and landfill sites, waste management plants were required to have a visual inspection system for the storage and/or landfill site. Monitoring should be carried out 24 hours per day with the use of technical devices of the control system that meet at least the requirements of the PN-EN 62676-4:2015-06 standard. In order to ensure adequate fire protection and minimize the negative impact on the environment, the need to modernize waste storage places has been regulated by legal acts – Regulations of the Minister of Climate of 11 September 2020 on detailed requirements for waste storage (Journal of Laws 2020, item 1742) and the Minister of the Interior and Administration of 19 February 2020 on fire protection requirements to be met by construction objects or their parts and other places intended for the waste collection, storage or processing (Journal of Laws of 2020, item 296). The regulations define requirements for the technical infrastructure of waste storage places and the necessity to equip them with ventilation systems and high-speed gates. The amendment to the Act on waste also shortened the allowed waste storage time from 3 years to a year. This change had a particularly negative impact on the management of raw materials for recycling and the combustible fraction converted into alternative fuel, the production of which exceeds market demand. The tightening legal requirements for conducting waste management processes and the costs associated with their implementation resulted in the closure of many industrial enterprises related to

waste recycling. The literature also points to the problem of some Asian secondary raw material collector closures [10]. The reduced demand for secondary raw materials and the shortening of their possible storage time are not conducive to increasing the profits from their sale. Regarding the costs of waste processing, the above-mentioned administrative and legal guidelines forced the purchase of additional devices, construction of telecommunication infrastructure (including optical fibres), modernization and expansion of existing waste storage facilities, and more frequent transfer of waste for further management to external entities. All these activities, with the simultaneous lack of an increase in the market value of secondary raw materials, resulted in an increase in the costs of waste processing, including waste transportation, personnel charges, and investment. The above dependencies are reflected in the structure of waste management system costs in the analyzed cities. In Cracow, from 2020, a smaller stream of mixed waste is sent for thermal processing. At the same time, increased amounts of the waste staying after sorting and mechanical-biological processing are processed in the plant. The above-mentioned actions aim to increase the degree of raw materials recovery and to reduce the time of waste storage. For cities that do not have installations for thermal waste treatment, limiting the mass of stored and temporarily stored waste is more difficult to implement. For this reason, Opole and Gdansk recorded a higher increase in the cost of waste processing than Cracow.

The cost of waste treatment is also strongly influenced by the electricity price, which has been steadily increasing recently – both for households and enterprises [20]. The electricity rate for enterprises in 2019 was approximately PLN 0.32/kWh net, and currently, it is around PLN 0.70/kWh net. Electricity costs consist of two factors, i.e., the free-market cost of buying electricity and the cost of its distribution approved by the President of the Energy Regulatory Office – fixed for all companies settled within a specific tariff group [21]. Therefore, it can be noted that in Poland electricity prices for enterprises are not fully regulated. They are mainly determined individually by service companies' offers, but in recent years the proposed electricity rates are much higher [21]. Expanded electricity costs are influenced by both factors related to the more expensive operation and the distribution systems maintenance, as well as higher employment costs, rising inflation, demand for energy, costs of its production, and prices for CO<sub>2</sub> emission allowances.

Another factor influencing the costs of waste processing is the interest rate deciding the leasing costs of vehicles and equipment. In the first stage of the COVID-19 pandemic, the Monetary Policy Council significantly lowered the NBP reference rate to 0.1%. Nevertheless, since October 2021, it has been growing steadily, especially since the first quarter of 2022. Currently, the reference interest rate is 6.75% [22]. The constantly observed increase in prices may determine the extension of the interest rate increase cycle, and the first reductions to the current value of the reference rate may not appear until the end of 2023.

#### 4.3. MANAGEMENT

The national economic situation affects the costs of managing municipal waste management systems. One of the factors determining this type of cost is the amount of the minimum wage, which has been steadily increasing in recent years. In addition, the increase in salaries, and thus employment costs, applies to all positions in enterprises, in particular the sector of physical workers and industry specialists who deal with scarce professions on the labour market (e.g., drivers, machine operators).

Another factor influencing the managing system cost was the introduction, under the Act on waste, the necessity to keep records of waste and their transfer cards in the BDO system (Database on products and packaging and waste management). BDO was launched on 1 January 2020 as a combination of the register BDO and recording and reporting modules, which involved the need to hire new people to use the system and/or train employees who previously dealt with reporting in municipal waste management companies. In addition, in terms of system management costs, the implementation of new guidelines for running such systems is also important. Moreover, the 2018 amendment to Act on waste introduced the obligation for enterprises to have fire protection plans. It is a document necessary to issue a permit for waste collection and processing. In addition, it should define the fire protection conditions of the facility/installation and waste storage places. The document must be prepared by an authorized fire safety appraiser. The limited number of people with such authorizations and the lack of detailed regulations specifying the template of such a document resulted in the high cost of preparing the reports.

#### 5. CONCLUSIONS

Waste management costs include many aspects directly related to the implementation of the waste treatment process and external factors. In the period 2017–2021, there was an increase in the costs of running a waste management system for the three analyzed cities by approximately 40–60%. A lower cost increase was recorded for Cracow, which processes waste in MBP and THR technologies.

Currently, the collection and transport of waste, its processing, and system management have the strongest impact on waste management costs. The charges of the above-mentioned stages of waste management are shaped primarily by the current fuel and electricity prices and staff costs. As presented in Section 4, the costs of these components have increased significantly in recent years, which has transformed into an increase in the overall costs of enterprises' operations. Changes in the national legislation, mainly related to the circular economy implementation and better environmental protection, impose more and more restrictive requirements for selective waste collection and reduction of landfilled waste mass. These activities force the waste sector enterprises to implement new technological solutions as well as expand and modernize the



existing technological lines. To improve the country's waste management system many investments are planned in the coming years, estimated in total at over PLN 24 billion. These investments will be financed from EU funds, the state budget, and enterprises' funds. An important factor, which also strongly influences the prices of waste processing, is the environmental fee paid during waste landfilling. From 2019, the fee amounts to PLN 270/t of landfill waste, and it is expected that it may shortly increase. Unfortunately, the complete elimination of landfilling is impossible to achieve. In Poland, there is also a relevant problem with the management of the combustible fraction staying after the separation of raw materials for recycling, which, according to the law, should not be landfilled. The current market situation shows that the amount of waste-based alternative fuel production exceeds the real demand and the processing ability of the available thermal installations. In addition, the 2018 Act on waste amendment shortened the allowed waste storage time from 3 years to one year, which intensified the problem with combustible fraction management and reduced the market value of secondary raw materials. The amendment to the Act on waste also introduced the obligation to monitor landfills and waste storage sites. The lack of appropriate system solutions at the national level and the introduction of restrictive requirements for storage and waste disposal cause a systematic increase in waste processing costs.

The above-described factors contributed to significant growth in the operating costs of waste management sector enterprises in the country. In the following years, a further increase in waste management costs is expected, reinforced by planned investments in the installation construction, and modernization. Covering the costs of waste management operation systems will be possible by enhancing the budgetary resources for this type of activity and increasing the waste fees incurred by waste producers. Under national regulations, cities that have recorded a positive financial balance in the waste management sector in recent years may only use the funds for activities related to waste management. It is therefore possible that in these cities the increase in waste fees will be not as rapid as in other cities.

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