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Sustainable Municipal Waste Management during the COVID-19 Pandemic—A Case Study of Poland

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Abstract: With the outbreak of the COVID-19 pandemic, the waste management sector had to face new challenges, e.g., changes in the size and composition of the waste stream, or the presence of potentially infectious waste. This article is based on a case study in Poland. The data analysis showed that the increase in municipal waste mass during the pandemic did not differ from statistics observed in previous years and ranged from 0.3 to 0.5 million tons per year. Lifestyle changes caused a decrease in the amount of waste generated outside households. Social migrations contributed to rapid changes in the mass of waste generated in selected agglomerations by up to 80 kg/capita. In the waste stream, significant amounts of specific groups of waste related to the pandemic ("corona waste") as well as packaging and food waste were noted. Despite the pandemic, in 2020, Poland recorded an increase in selective waste collection by 6.7 percentage points (pp.) Data on municipal waste management showed an increase in the mass of waste sent for recycling by 0.7 million tons, while the mass of landfilled waste decreased by 0.3 million tons. The observed positive changes in waste management allow the implementation of sustainable development assumptions to a greater extent.

Keywords: municipal waste; waste management; COVID-19 pandemic; circular economy; sustainable development goals

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1. Introduction

The main idea of sustainable development (SD) is to meet modern society's needs without limiting development opportunities for future generations. It is a process that connects socio-economic areas with ecological balance and environmental protection. Among the 17 main sustainable development goals (SDGs) set by the United Nations, all aspects of human life and economic activity have been taken into account [1]. The three main pillars of sustainable development include social, economic, and environmental aspects [2]. The challenges of achieving the SDGs are faced both by highly developed and developing countries that are recently implementing the correct procedures, legislation, and technologies [3,4]. These countries usually have limited financial resources, so the transition toward sustainable development is not as fast as in developed countries [3].

One of the key elements of implementing SD principles is correct waste management. According to SDG 12. Sustainable production and consumption, "Governments and all citizens should work together to improve resource efficiency, reduce waste and pollution, and shape a new circular economy". The circular economy should cover every step of production and consumption, reducing the use of raw materials, water, and energy, and minimizing waste production. In the field of waste management and prevention, the minimization of landfilling and the maximization of reuse and recycling should be implemented [5]. Reaching SDG 12 requires a comprehensive operation from policy-makers,

businesses, researchers, and consumers, and cooperation between them. Proper waste management also impacts goals directly connected with environmental protection, e.g., the protection of marine resources (SDG 14), terrestrial ecosystems, and biodiversity (SDG 15), as well as preventing climate change (SDG 13). Social aspects, such as ensuring adequate sanitation and minimizing the release of hazardous chemicals (SDG 6), are also important.

Municipal waste management is one of the most important parts of global environmental protection systems affecting the life of society and the economic sector. Constant technological progress, industry development, the growing requirements of users, and life in the era of increased consumerism determine the continuous growth of various types of products and services, and thus also waste. Therefore, the overriding task of local waste management systems is ensuring legal regulation in the context of proper waste processing and the use of the obtained secondary raw materials while providing environmental protection [6–10].

Waste management should be based on the waste hierarchy, which defines the desired directions of their treatment. According to the hierarchy, waste prevention should be the main priority. Next, the waste processing should be in line with the assumptions of a circular economy, which promotes a departure from the "take–produce–consume–dispose" model in favour of the 5R model "reduce, reuse, recycle, recover, renew" [11–13]. These activities include waste preparation for reuse, recycling, and other forms of recovery (including energy recovery). As mentioned, the basis of the waste hierarchy is the reduction or rather the absence of waste generation, followed by recycling and recovery of raw materials. Nevertheless, there is still a visible trend that puts emphasis on properly conducted waste management based on effective processing. This approach is not incorrect because it represents a significant improvement in the performance of waste management systems where they are treated as potential sources of secondary materials (from the linear model towards the circular economy). Thanks to this, the raw materials contained in the waste can be recovered and still be present in closed-loop systems. However, it should be noted that the operation of the circular economy model, in addition to reducing the consumption of natural resources and replacing them with secondary raw materials from waste, is also based on the appropriate design of products and technologies. This, in turn, will have an adequate impact on waste generation and its subsequent management, where the basic condition is primarily to reduce its generation [14–18]. The last, and least desirable level of the hierarchy is waste landfilling.

The basic act regulating waste management in Poland is the Act of 14 December 2012 on Waste, which defines municipal waste as waste generated in households and waste from other sources with similar compositions and properties. The communes are responsible for organizing the municipal waste collection and processing system, which is regulated by the Act of 13 September 1996 on maintaining Cleanliness and Order in Communes. Under the Act, municipal waste should be collected selectively, as this enables its reuse and/or recycling. The separate collection system should cover the fractions of paper and cardboard, glass, bio-waste and plastics, metals, and multi-material waste. The Act provides for the achievement of specific levels of municipal waste selective collection and also specifies the degree of limitation of waste landfilling.

Several legal restrictions governing the functioning of waste management systems are not able to prevent sudden changes caused by social and/or economic crises. In recent years, the rapid spread of the infectious coronavirus SARS-CoV-2 has had the greatest impact on municipal waste management. In the face of the COVID-19 pandemic threat, the priority in making waste management decisions was to prevent the spread of the disease, which was not always in line with SD assumptions. The need to react quickly and the lack of sufficient knowledge about the SARS-CoV-2 virus, especially in the initial phase of the pandemic, contributed to rapid changes in the quantitative and qualitative waste composition and the place of waste generation.

This article, based on an in-depth review of the available literature on the subject and various source data, discusses the challenges of municipal waste management during the

COVID-19 pandemic. Based on the analysis of statistical municipal waste management data in Poland in 2017–2021, an attempt was made to identify the real pandemic impact on changes in the quantitative and qualitative waste composition as well as methods of waste processing. The results were compared with the current policy in the waste management sector, taking into account the circular economy and sustainable development. Based on the analysis of literature data, the most important goals and tasks of waste management in the period of epidemic threat or similar crises were also indicated to contribute to the proper development of long-term effective management systems.

2. Challenges in Municipal Waste Management during the COVID-19 Pandemic

The pandemic started in early March 2020. With each passing day, social life, as well as economic, cultural, and educational activities, were more and more limited. Since then, there have been new waves of disease in Poland resulting from the presence of new variants of the SARS-CoV-2, and the Polish government has been continuously mitigating or tightening the restrictions resulting from the epidemic situation in the country.

The difficult epidemic situation, especially in the initial phase of the COVID-19 pandemic, had a significant impact on social and economic life, including waste collection and treatment systems. Quantitative and qualitative changes in the waste stream and problems with their proper processing were initially observed primarily concerning medical waste due to increased hospitalizations of patients infected with the SARS-CoV-2 virus. The increase in the medical waste amount, especially those with infectious properties, has conditioned rapid action in the field of proper management of this type of waste. In Poland, in 2020, preventive actions were taken by introducing the possibility to designate additional storage space at entities processing medical waste, increase the capacity of hazardous waste incineration plants, and dispose of medical waste in non-hazardous waste incineration plants (i.e., with installations with technical the possibility of safe incineration of such waste, but without appropriate administrative decisions in this regard) [19]. Nevertheless, based on the review of available reports, as well as our observations, it can be concluded that during the COVID-19 pandemic, most changes and challenges appeared related to municipal waste management (Figure 1). These include, above all, changes in the quantitative and qualitative composition of waste, the occurrence of fractions strictly related to the pandemic (mainly masks), waste management during isolation and quarantine, and ensuring their proper collection and processing. It can therefore be concluded that the most important challenge was to find solutions that prevent the spread of the virus and at the same time fit in with the general principles of SD, including the circular economy.

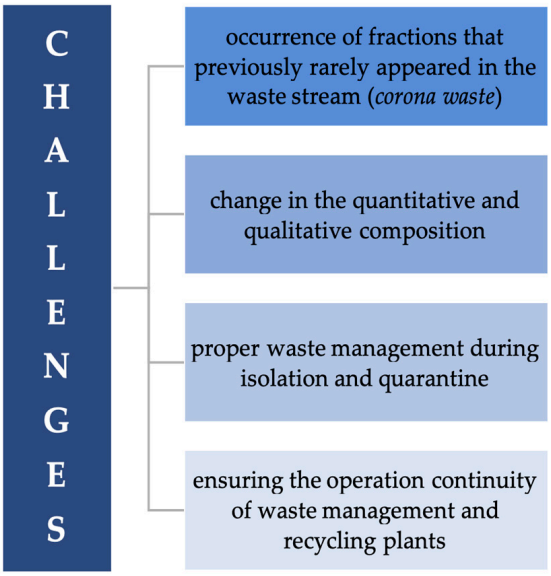

Figure 1. New challenges in municipal waste management emerged during the COVID-19 pandemic.

From the first reports on the appearance of the SARS-CoV-2 infections and the possible course of the disease (not fully recognized, but certainly a quick mode of disease transmission; quarantines, isolations; often required hospitalizations of patients), it was known that this would have an impact on various aspects of everyday life, including municipal waste management. Many doubts arose on the part of system users, including what to do with used personal protective equipment (PPE) and other waste during quarantine or isolation, or whether waste still needed to be segregated as in the pre-pandemic period. In addition, the transfer of virtually all everyday life to home through remote work, the closing of restaurants, the temporary introduction of restrictions on movement, etc., resulted in not only quantitative but also qualitative changes in the municipal waste stream. It could be expected that the amount of paper and plastic packaging waste would be much higher than in previous years. The composition of municipal waste from households also includes waste so far rarely found in this group—masks, gloves, packaging for disinfectants, and COVID-19 home tests—so-called "corona waste". In addition to the emergence of waste problems for everyday users, the COVID-19 pandemic has had a significant impact on the waste-related economic sector. As in other enterprises, also in waste neutralizing and/or processing plants, the challenge was to ensure the continuity of the system, i.e., unchanged or even more frequent waste collection, adjusting the work schedule of staff depending on epidemic conditions or guaranteeing the efficiency of plants in terms of the increased amount of waste received.

3. Counteracting the Impact of COVID-19 on Waste Management—Municipal Waste Management Principles during a Pandemic

The change in the amount of municipal waste due to the ongoing COVID-19 pandemic and the potential risks associated with their processing have forced countries to make sudden decisions about waste management to ensure the continuity of the proper system functioning and to meet new challenges in this area, such as the classification of PPE waste. In order to systematize the operation of the waste management system during a pandemic, the world's largest organizations have issued a number of guidelines in this area. The World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) indicate that COVID-19-related waste can be divided into two types: from health facilities and other, e.g., municipal waste. Medical waste should only be treated in facilities specifically designed for this type of waste and handled with care due to its potentially hazardous properties. Everyday use of PPE waste qualifies as harmless municipal waste [20].

In Poland, the Minister of Climate and the Chief Sanitary Inspectorate developed special guidelines for managing waste generated during the pandemic (Guidelines of the Minister of Climate and the Chief Sanitary Inspector). The document contains general rules for waste management and detailed information for municipalities, healthy people, people in quarantine or isolation, and entities dealing with waste management. The guidelines clearly regulated the issue of proper disposal of used PPE by healthy people—they should be thrown into the mixed waste stream. In addition, attention was drawn to problems with classifying waste from quarantine or isolation—due to the place of its generation, it should be treated as municipal waste, but it is necessary to take special precautions when managing this type of waste. The guidelines for municipalities mainly concern their obligations in the field of waste management. During the COVID-19 pandemic, municipalities should, if possible, provide bags of appropriate colours and/or marked with an appropriate symbol (e.g., "C") so that waste from people in isolation can be easily identified. Moreover, these bags should be collected at least every 7 days and sent directly to municipal waste processing installations. Another group of waste included in the discussed guidelines is waste generated in quarantine facilities. This type of waste should be segregated according to the applicable rules, and PPE should be collected in extra bags and thrown into the mixed waste stream. The most detailed guidelines have been set out for the management of waste from isolation sites. Bags with this waste should be filled

to a maximum of three-quarters of their capacity, kept for 72 h and then sprayed with the virucidal agent before being handed over to the person collecting the waste from the person in isolation. After collecting the waste, this person should pack it in a second bag, note the date and time of closing the bag, and place the bag at the waste collection point, preferably in a special container for this type of waste.

Due to the high risk of virus infection, waste management companies are obliged to protect the health of their employees. Workers who come into direct contact with isolation waste must be equipped with PPE and antibacterial gels, and the places where the workers stay should be systematically disinfected. According to the guidelines, waste is no longer a hazard after 9 days; therefore, it is recommended to store it for nine days before processing. It is also extremely important to ensure the continuity of the waste management systems. Therefore, it was determined that in the event of a staff shortage caused by the COVID-19 pandemic, it is recommended to reduce the frequency of separately collected waste collection and to ensure, in particular, the treatment of isolation waste, mixed waste and biowaste. In the case of isolation waste, it is recommended to process it on fully automated lines (without human intervention), and if there is no such possibility, it should be sent directly for disposal—in thermal conversion processes or storage in landfills with active degassing installations.

In addition to Poland, other countries have also introduced their own additional rules for waste management during the COVID-19 pandemic. In Austria, the main focus was on waste facilities workers. Elderly and/or chronically ill workers were relieved of their duties during the peak wave of the pandemic, and urban cleaners were hired to help. Many countries asked residents to separate used face masks, gloves, and other PPE from other household waste to ensure the safety of workers at waste management facilities and to prevent the uncontrolled spread of the virus. In Romania, residents segregated contaminated waste into separate bags. In turn, the Greek authorities, due to the spread of the virus, asked the public not to go to separate waste collection and recycling points [21].

4. Analysis of Changes in the Quantitative and Qualitative Composition of Municipal Waste

4.1. Municipal Waste Generation in Poland

The outbreak of the COVID-19 pandemic caused a sudden change in the lifestyle of society, which may also cause changes in the waste management system. As mentioned in Section 1, municipal waste, apart from waste generated in households, includes waste generated in places where people stay, i.e., in workplaces, public spaces, and recreational places. The strong limitation of stationary work and social life immediately after the outbreak of the pandemic influenced the size, place of generation, and composition of the municipal waste stream [22,23]. People spent more time at home, which reduced the amount of municipal waste generated from other sources. Such observations are confirmed by literature reports [20]. Figure 2 shows the Statistics Poland data on the size of the municipal waste stream from households and other sources in 2017–2021.

As shown in Figure 2, the mass of municipal waste generated in 2020 and 2021 did not differ from the values recorded for the previous years. In line with the trends observed in recent years, the mass of municipal waste generated in Poland in 2017–2021 has been gradually increasing, and households were the dominant source of municipal waste generation. The annual increase in the mass of municipal waste generated in 2017–2021 ranged from 0.3 to 0.5 million tons. In 2020 and 2021, during the COVID-19 pandemic, a decrease in the mass of municipal waste generated outside households was observed. The share of this waste in the total municipal waste stream was <14%, which was a lower result than in the previous years (15.5–16.7%). The mass of municipal waste from sources other than households generated by one inhabitant in 2020 and 2021 was 48 kg/year and 50 kg/year, respectively, which was a decrease of 2 to 5 kg in relation to the pre-pandemic years.

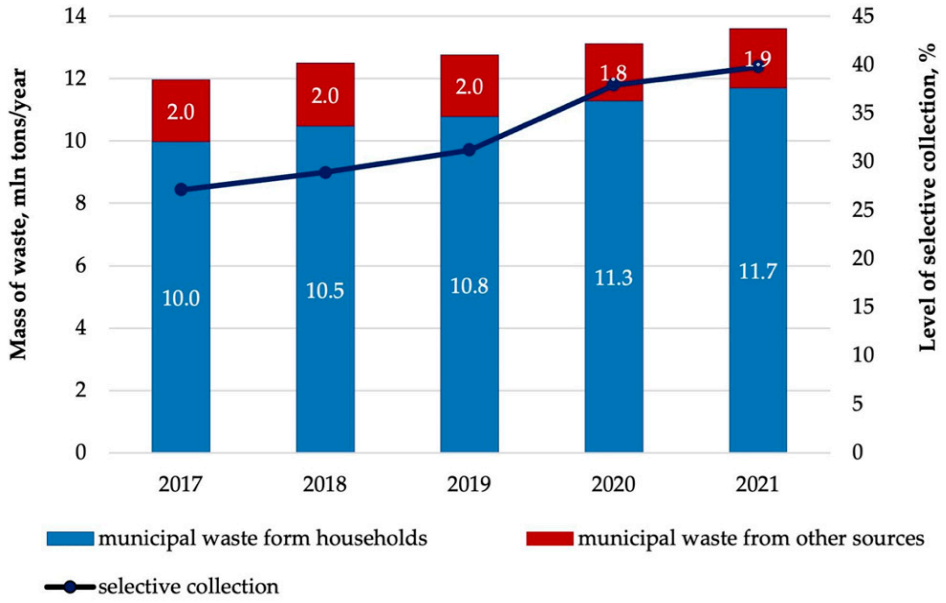

Figure 2. Mass of municipal waste from households and other sources generated in Poland in the years 2017–2021, based on [24].

Despite the difficulties caused by the pandemic outbreak, in 2020 and 2021, there was a further increase in the levels of selective collection achieved, which is a positive phenomenon in the context of the SD idea implementation. Nevertheless, during the period of strong lockdown (the beginning of the pandemic), in some regions, a decrease in the efficiency of selective waste collection was recorded, mainly due to the delay in issuing guidelines on waste management during the pandemic (issues related to the correct disposal of corona waste or segregation during quarantine/isolation) [21]. Therefore, this problem caused the deterioration of selective waste collection, which affected the statistics in this area in the initial, hard phase of the lockdown [21]. In addition, it should also be remembered that, for safety reasons, in some countries, a larger mass of waste was sent for incineration instead of other treatment methods, including recycling, which was also indicated in the guidelines for Poland. The statistics of waste generated during the pandemic also show greater amounts of infectious medical waste, which are disposed of by thermal treatment [13]. In general, it can be concluded that in the initial phase of the COVID-19 pandemic, there was a lot of chaos in the field of waste management, which affected the selective collection of waste but did not cause long-term negative effects in this regard. In the pre-pandemic period, an increase in the levels of selective collection was observed every year. However, during the pandemic, a sharp rise in selective waste collection was recorded (Figure 3). In 2020, compared to the previous year, a 6.7 pp. increase in the municipal waste selective collection levels was observed, which was caused mainly by the obligation to selective bio-waste collection. Residents started a selective collection of waste from the kitchen and garden, which automatically increased the level of selective collection expressed in relation to the mass of waste generated. At the turn of 2019/2020, the mass of selectively collected bio-waste increased by over 413 thousand tons, i.e., by almost 35% (Figure 3). The increase in selective waste collection during the pandemic was also a result of the change in the lifestyle of society, including, above all, the popularization of online shopping. These changes contributed to an increased mass of generated packaging waste made of plastics, paper, and cardboard. These fractions were already the main components of the selectively collected waste stream before the pandemic. According to the Statistical Office [24], the masses of separately collected paper and cardboard waste and plastics amounted to 499.2 and 491.2 thousand tons, respectively, and were 43.2% and 23.8% higher than in 2019 (Figure 3). Overall, for these three fractions of selectively collected municipal waste over the years 2019–2020, the increase in mass amounted to almost 660 thousand

tons, whereas in previous years this increase did not exceed 330 thousand tons per year. It can therefore be concluded that the COVID-19 pandemic has influenced the observed changes in the masses of selectively collected waste, especially in the case of paper and plastic waste, for which no new important legal regulations have been introduced in Poland in recent years. During the pandemic, online shopping and home food ordering enjoyed great interest, which generated an increase in the amount of packaging. This waste has been collected selectively in Poland for years, so it can be expected that thanks to the environmental awareness of the society, high results for selective collection were recorded in the analysed period. In addition, it should be noted that the overall increase in the mass of waste generated in Poland during the pandemic was not greater than in previous years (the growth trend was maintained), while the mass of selectively collected waste increased. A particularly significant increase in the mass of selectively collected waste was achieved in 2020, i.e., during the largest pandemic lockdowns, which may prove the correlation of these phenomena.

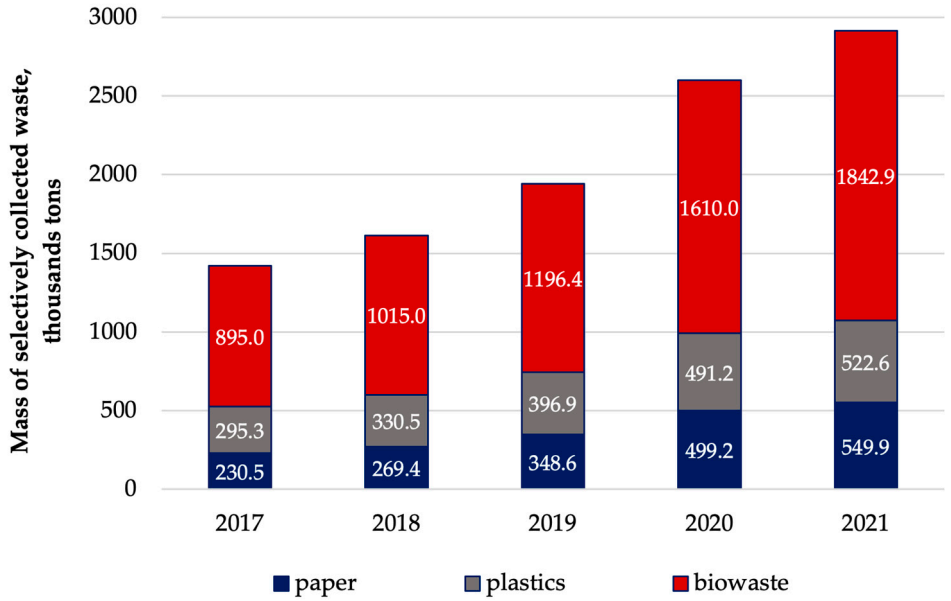

Figure 3. Mass of paper, plastics and biowaste collected selectively in Poland in 2017–2021, based on [24].

The nationwide increase in the mass of municipal waste generated during the pandemic, shown in Figure 2, is not the only indicator worth considering in the context of changes in the waste balance. In connection with the change in the mode of work and study in the country, internal migrations in the society were observed. This aspect mainly concerns academic cities and student communities, which in 2021 numbered over 1.2 million people [24]. For economic and social reasons, students returned to their family homes, which reduced the mass of municipal waste generated in academic cities. Changes in the mass of municipal waste generated per capita in the six largest academic cities in Poland in 2019–2021 are presented in Figure 4 (data for previous years are not available).

As shown in Figure 4, in the analysed academic cities, apart from Warsaw and Kraków, in 2020, there was a significant decrease in the mass of waste generated per capita compared to 2019. The largest decrease in the mass of waste was recorded for Wrocław (−87 kg/capita) and Gdańsk (−84 kg/capita). Moreover, the mass of waste generated in four academic cities in 2021 was also lower than in 2019. The largest decrease in the mass of waste generated per capita in 2021 was recorded for Łódź (−43 kg). The decrease in the mass of waste in large academic agglomerations increased the mass of municipal waste generated in smaller towns. An example is the city of Konin, located between Poznań and Łódź, where the mass of municipal waste generated per capita in 2020 was 65 kg bigger than in 2019. In Oława, located near Wrocław, the increase in waste mass per capita was 71 kg [24]. Rapid changes

in the mass of waste could cause difficulties in processing it whilst following the circular economy principles.

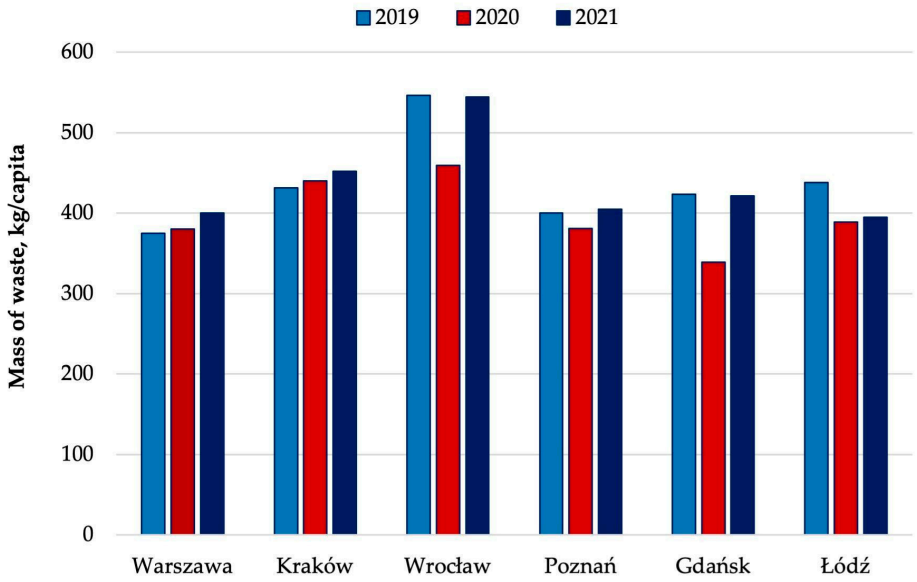

Figure 4. Mass of municipal waste generated per capita in the largest academic cities in Poland in the years 2019–2021, based on [24].

Similar correlations in the mass of waste generated before and during the pandemic were also observed in other Central Europe countries. In the Czech Republic from 2017 to 2021, as in Poland, a slow gradual increase in the mass of municipal waste was recorded [25]. The pandemic did not contribute to a sharp increase in the mass of municipal waste in 2020 and 2021. Some Czech regions recorded significant fluctuations in the mass of waste generated per capita. For example, the capital city of Prague noted a decrease in the mass of waste of 43 kg/capita, while an increase of 48 kg was recorded in the adjacent Central Bohemian Region. In Slovakia [26], in 2019–2020, there was a 10.2% increase in the mass of municipal waste generated. However, the available data show that an increase of almost 9% was also recorded between 2017 and 2018, well before the pandemic. As in Poland, the levels of selective waste collection in Slovakia increased significantly during the pandemic. In 2020, the level of selective waste collection was 35.8%, which was an increase of 8.8 pp. compared to 2019. In 2021, the level was 38.8%. The above-presented data prove that the observations regarding the mass of municipal waste generated during the pandemic in Poland may be universal for other European countries with similar structures, societies, and economies.

4.2. Municipal Waste Treatment in Poland

The growing amount of municipal waste determines the need for proper management. This task seemed quite difficult during the COVID-19 pandemic, especially in its early stages. The coronavirus infection risk and frequent quarantines and/or isolations of plant employees could be the reasons for problems in the proper processing or disposal of municipal waste. As mentioned in Section 2 (Figure 1), the expected increase in the waste amount coupled with problems with the established operation of treatment plants could have a potential impact on the entire waste management system, especially regarding waste processing. Figure 5 shows the mass of municipal waste generated in Poland in the years before (2017–2019) and during (2020–2021) the pandemic, taking into account the method of management.

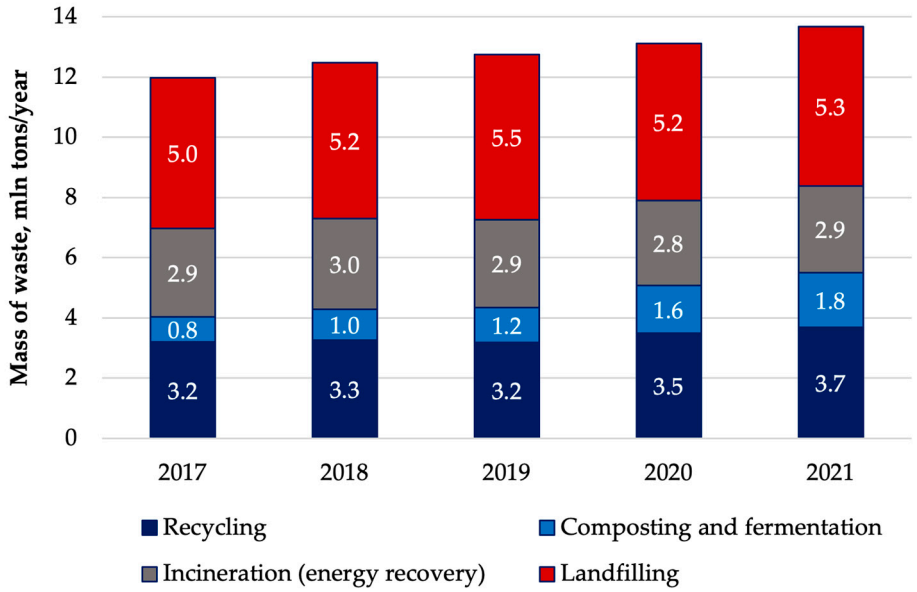

Figure 5. The mass of municipal waste generated in Poland in the years 2017–2021 by the method of its management, based on [27].

In Poland, the methods of processing and neutralizing municipal waste are classified into four categories: recycling, composting and fermentation, energy recovery through incineration, and landfilling (Figure 5). Since 2017, the largest amount of municipal waste in Poland has been landfilled (on average, approx. 40% of the generated municipal waste mass). Nevertheless, it should be noted that the amount of landfilled waste changes slightly over the years—in 2020 and 2021 (pandemic years), less than 39% of the mass of all generated municipal waste was landfilled. This means that despite the increase in the mass of waste, this waste was more often processed in other ways. Since 2017, there has been an increase in the mass of municipal waste recycled, composted, and fermented, even in the years closely related to the COVID-19 pandemic (2020–2021). Compared to 2019, in 2020, there was an increase in the mass of waste sent for recycling, including organic recycling, by 0.3 and 0.4 million tons, respectively. In those years, the increase in the amount of biowaste and other selectively collected waste (e.g., paper or plastics) could have been conditioned by the behaviour of system users during the pandemic (more frequent stays at home—stockpiling food, cooking meals; online shopping—packages in cardboard boxes). Due to the fact that they are managed through organic (biowaste) or material recycling (plastics, paper, etc.), a greater increase in the mass of municipal waste processed in this way in 2020–2021 compared to until 2019 was also noticed. In addition, the mass of municipal waste intended for energy recovery by incineration remains at a constant level (2.8–3.0 million tons/year). This is because of the fact that in Poland most municipal waste incineration plants were built in 2015–2018. Construction of new facilities is expected to start in the near future, but it is constantly opposed by Polish society, which reflects the mood of other European countries' residents [28–30].

The situation related to the municipal waste management methods used in Poland is similar, especially to the systems of other Central European countries the Czech Republic or Slovakia. When analysing Eurostat data [31], it was noticed that, similarly to Poland, waste in both the Czech Republic and Slovakia is most often landfilled (approx. 45% of the mass of municipal waste generated). They are also largely recycled and composted (approx. 40%). On the other hand, compared to statistical data for Poland, a much smaller proportion of municipal waste is incinerated (Czech Republic—approx. 12% of the mass of municipal waste, Slovakia—approx. 1%, Poland—approx. 20%). In turn, in comparison to the average statistical data for the European Union, out of the total mass of municipal waste generated in the Member States in 2020, 48% of it was recycled or composted, 26% was incinerated, and 24% was landfilled [31]. It can therefore be concluded that both the

management methods and the generated municipal waste mass in Poland are close to the average EU values achieved in similar periods of time.

4.3. Corona Waste

The risk of rapid infection with the SARS-CoV-2 virus has been limited by the introduction of the obligation to use PPE, in particular masks to cover the mouth and nose, as well as the optional use of disposable gloves in the initial phase of the pandemic. A typical disposable surgical mask used in healthcare facilities, but also by ordinary users on a daily basis, consists of many materials, including plastic nonwovens, filtering layers and a wire that allows it to fit the face. In the later stages of the pandemic, reusable textile masks were also used. Disposable gloves are usually made of latex, synthetic rubber, polyvinyl chloride, or polyethylene. Other commonly used personal protective equipment also includes liquids, gels, and wipes, the use of which is still being observed.

The increased demand for PPE determined the need to produce the required amounts of this type of equipment. In Poland, from the beginning of the COVID-19 pandemic to June 2022, statistics were kept on the production of industrial products related to preventing the spread of/combating COVID-19 (Table 1). Business entities employing 50 or more people took part in the monthly survey [32].

Table 1. Production of selected industrial products related to preventing the spread of/combating COVID-19 [32].

Product	Unit	3–12.2020	1–12.2021	1–6.2022	Total
Protective clothing	millions of pieces	9.26	1.04	0.09	10.40
Protective face masks for medicine	millions of pieces	43.43	62.85	274.23	380.52
Other protective face masks	millions of pieces	175.89	97.69	66.98	340.55
Rubber gloves	millions of pieces	0.59	-	0.03	0.62
Foil gloves	millions of pieces	3.54	0.10	-	3.63
Protective headgears	millions of pieces	7.35	-	0.73	8.08
Face shields	millions of pieces	11.45	0.70	0.18	12.34
Protective glasses	thousands of pieces	70.37	-	-	70.37
Protective shoe covers	millions of pieces	8.28	-	-	8.28
Breathing apparatus and gas masks	thousands of pieces	-	15.20	2586.30	2601.50
Parts for respirators	tones	73.57	21.25	4.06	98.87
Disinfectant liquids and gels	thousands of tones	80.46	8.70	3.63	92.79
Disinfectant tissues	thousands of tones	12.87	0.06	0.25	13.18
Disinfectant soap	thousands of tones	6.12	21.02	11.85	38.98
Swab collection kits	millions of pieces	0.21	0.17	0.14	0.52

In 2020–2022, over 700 million masks were produced in Poland, half of which were protective masks for everyday use. Nevertheless, as the pandemic continued, the number of medical masks increased compared to other products of this type. It should be emphasized that in Poland at the end of March 2022, the obligation to cover the mouth and nose in most closed areas was abolished, while protective masks in medical facilities and pharmacies are still required. This explains the fluctuations observed in the statistics. In addition, fewer disinfectants (liquids, gels, and tissues) and protective gloves were produced in 2022 compared to in 2020, which is also closely related to mitigation and ultimately abandoning restrictions.

As the pandemic continued, in addition to the widespread use of personal protective equipment, disposable COVID-19 tests for self-testing at home or workplaces began to be used more often. Tests are available in pharmacies, supermarkets, and through online sales. The data contained in the PEX PharmaSequence reports present information on COVID test sales from about half of the pharmacies in Poland, i.e., from 6200 facilities. As shown in Figure 6, the highest test sale was observed in January 2022, when the largest wave of cases was recorded in Poland and worldwide. An increase in test sales can also be observed in December 2021 and 2022, i.e., in the pre-Christmas period, associated with frequent family visits and travelling. The number of tests sold in pharmacies during 18 months

of the pandemic (from September 2021 to February 2023) amounted to over 12 million. Considering the fact that there are over 12,000 pharmacies in Poland, and the tests are also available in other facilities, the actual number of tests sold is several times higher.

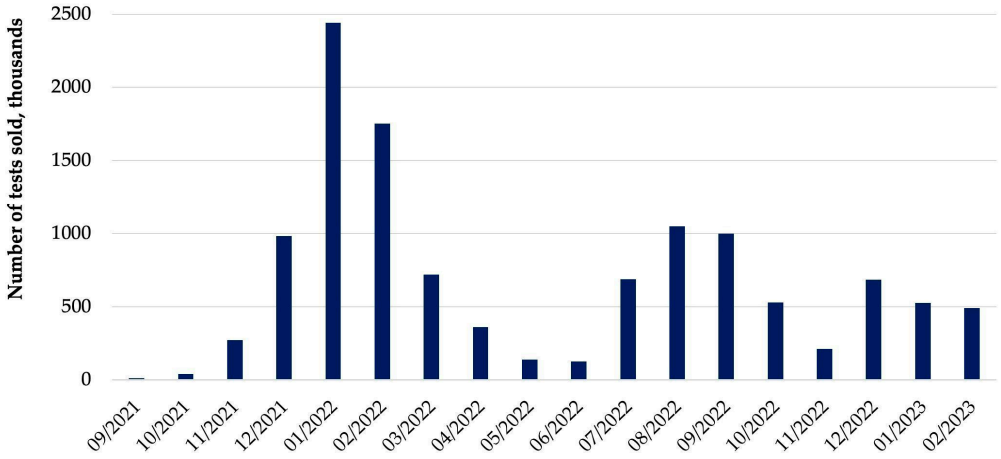

Figure 6. The number of tests for COVID-19 sold in pharmacies in Poland between September 2021 and February 2023, based on [33].

The global situation regarding the spread of coronavirus also had an impact on the management of waste directly related to the pandemic, so-called "corona waste". The amount of used PPE and home tests translate into the amount of this type of waste, the proper management of which was crucial for environmental protection. As it turned out, during the pandemic, waste masks and gloves were often improperly disposed of by users, thus polluting the water and soil environment and posing a threat to the health and life of wild animals [34]. As mentioned earlier, over 700 million masks were produced in Poland during the two years of the pandemic (Table 1). It is estimated that, in India, the amount of such waste per week was more than 4500 million individual pieces of waste per week; in the United States, 1070 million pieces per week; and in the United Kingdom, 212.5 million pieces per week [35]. The results of a survey conducted by Selvaranjan et al. showed that up to 20% of respondents admitted to throwing away waste masks anywhere, 3% of people flushed them down the toilet, and 10% burned them. A total of 34% of the respondents disposed of the masks correctly—into mixed waste containers [25]. This means that the problem of corona waste management, especially waste protective masks and plastic pollution, was huge all over the world [36–39]. Apart from environmental threats, this situation also causes health security issues, because improper management of this type of waste may also carry the risk of secondary spread of the virus [40]. Therefore, a quick response to the problem in corona waste management was vital, also due to the long-term consequences in terms of meeting the requirements of sustainable development and the circular economy, as well as building the ecological awareness of the society.

4.4. E-Commerce and Packaging Waste

The restrictions introduced by the national authorities to reduce the speed of the coronavirus spread have focused mainly on closing restaurants, cinemas and theatres, shopping malls, and other places where people gather. The closure of traditional stores resulted in the popularization of online shopping. According to the OECD report, the share of the E-commerce industry in retail trade at the turn of the first and second quarter of 2020 was characterized by a strong increase (OECD 2020). Not only were clothes, footwear, and home electronics bought online but also food products for home delivery, which was not very popular before the pandemic. According to the literature, in the first two weeks of the pandemic, as many as 14% of Poles decided to buy groceries online [41]. In countries such as Germany, China, India, and Italy, online shopping increased on average from 12 to 57% during the pandemic [42]. Research conducted in Korea reports that online sales

of food and household products increased by around 20% during the pandemic [20]. The E-commerce industry maintained the supply chain between producers and consumers during a strong lockdown [43].

The development of the e-commerce industry is not without significance in the context of SD. The main aspect is the impact of deliveries on the environment (emissions, carbon footprint, waste) [44]. However, during the pandemic, the main focus was on supplies' security and liquidity to ensure people's needs. To provide health security for consumers and suppliers, courier companies have implemented many new solutions, e.g., contactless delivery, confirmation of the order receipt via the collection code or parcel collection from the parcel locker via the QR code [41]. The delivered products also require appropriate protection. This involves, in addition to the standard packaging and filling of consignments, additional packaging made of foil and/or cardboard. For example, groceries, due to health and hygiene concerns, during the pandemic period were additionally packed into films, foams, and/or multilayer plastics [45]. The mentioned activities increase the share of cardboard, plastic and composite materials in the municipal waste stream. Before the pandemic, Amazon already used over 10 billion packages each year [46]. The increase in sales recorded since 2020 (by 40% compared to 2019) resulted in an increase in the amount of packaging used. Palombini and Cidade [47] report that due to the development of the e-commerce industry in Brazil in 2020 and 2021, a significant increase in the amount of polymeric packaging waste was observed. In comparison to March 2019, in the early pandemic stages, packaged food sales in European countries such as Italy, France, and the United Kingdom increased even to nearly 70% [48]. The increase in the use of packaging products that turn into a waste stream is also confirmed by an increase in packaging production by 9% in 2020 and shortages of components for the production of packaging in 2021 [49]. The functioning of gastronomy only in the form of delivering meals "to go" resulted in similar dependencies [50]. Meals are usually delivered in polystyrene packages, aluminium foil, and/or plastic bags.

A positive aspect of the COVID-19 pandemic may be a wider scale of use and the development of more ecological packaging materials, such as biodegradable plastic polylactic [51] or green-based active packaging [52]. The pandemic has highlighted the need to develop new technologies to produce functional food packaging materials, ensuring food protection while having a low environmental impact [53]. Growing awareness of humans' negative impact on the environment may speed up the implementation of sustainable development in the everyday lives of people around the world.

4.5. Food Waste

Wasted food is one of the key components of the bio-waste stream generated by households. According to data from the Food and Agriculture Organization of the United Nations, about 1.300 million tons of food is wasted annually worldwide, which is a third of the world's total production [54]. Some literature reports point out the impact of the pandemic on changes in the amount of food waste. Pikoń et al. [55] indicate that in Poland at the beginning of the pandemic, i.e., in March and April 2020, in connection with making stocks of food, it was significantly wasted. Panic buying of food products was driven primarily by a reduction in the availability of food (e.g., limitation of movement, limits on the number of people in stores). Other studies have shown that the increase in food waste during the pandemic was caused by online grocery buying and frequent cooking [56]. However, in other publications, the authors indicate that in Korea [20] and Macedonia [57], due to the increase in the frequency of cooking at home, the amount of wasted food decreased. The relationships regarding the impact of a pandemic on the amount of food waste may vary from country and region, for example, depending on lifestyle, place of living, and the wealth of society [58]. Psychological, social and cultural factors are also important. An interesting example is the correlation study between food prices, the number of cases and shopping behaviour conducted in Japan. The results showed that in areas with a high number of infected people (large agglomerations), where food prices are higher

than in less populated areas, society implemented sustainable anti-food waste practices faster and more effectively [59]. Research conducted in Brazil [60] has shown that food price increases, caused by the pandemic, have popularized and strengthened proper food management practices already used in households. According to the literature [61], the pandemic may have a long-term positive impact on reducing food waste in the world, mainly through proper planning of grocery shopping and meal preparation. Behaviours such as reusing leftovers, organizing food by its expiration date, and using grocery lists are good practices that have become more common during the pandemic [62]. Increasing consumer awareness is a good step toward implementing the principles of SD against food waste.

5. Conclusions

More than three years after the outbreak of the COVID-19 pandemic, there is no doubt that it has created significant challenges for the proper management of municipal waste, which by applicable regulations should implement the sustainable development goals and waste hierarchy assumptions. When analysing statistical data presenting quantitative and qualitative balances of municipal waste generated in Poland in 2017–2021, it was noticed that despite the expected major problems in this regard, the COVID-19 pandemic did not have a negative impact on the amount of municipal waste generated. The mass of municipal waste generated in 2020 and 2021 increased by 0.3 and 0.5 million tons compared to the previous year, which is in line with the statistics from the pre-pandemic period. Lockdowns resulted in a decrease in the mass of waste generated outside households. Internal migrations within society caused changes in the mass of waste generated in large agglomerations and smaller towns adjacent to them, even by >80 kg/capita, which affected local waste management companies. Qualitative changes in the municipal waste stream were also observed. Personal protective equipment (PPE), the so-called "corona waste", before the pandemic has not been found in municipal waste or appeared sporadically. Lifestyle changes also affected the amount of packaging and food waste generated in households. Changes in the mass of waste depended on the region and social factors.

Data from 2020 show that at the turn of 2019–2020, a 6.7 pp. increase in the levels of selective waste collection was recorded. One of the main reasons for these positive changes is legal changes introducing the obligation of selective collection of municipal bio-waste. The level of selective collection of plastic and paper fractions, mainly from packaging waste, has also increased significantly. Data presenting the methods of municipal waste treatment in Poland also indicate an increase in waste recycling (mainly organic recycling) by 0.7 million tons, while landfilled waste decreased by 0.3 million tons. It can be said that the pandemic allowed for the popularization and strengthening of pro-ecological behaviour in waste management and the development of new technologies and solutions in the municipal sector. All activities undertaken in recent years have been in line with the circular economy principles, as well as the sustainable development goals. Reducing the mass of landfilled waste and increasing the levels of waste recycling and recovery meet the assumptions of SDG 12 and allow for a close loop in raw material circulation.

Currently, the situation related to the global pandemic has improved, and the WHO indicates that we are coming out of the extraordinary phase of the pandemic. The experience gained during the pandemic will contribute to the proper development of long-term management systems in waste management and faster and more effective responses in future risk situations. In the face of an epidemic threat, the priority in municipal waste management should be ensuring the continuity of waste collection. This requires the implementation of special safety procedures for employees in the waste management sector. It is also possible to temporarily limit waste management processes carried out with the participation of people, e.g., manual waste sorting processes [22]. Actions taken in such a situation must be adapted to the conditions of controlling and maintaining the highest safety standards, even if it does not comply with the standards set out in the waste management hierarchy [63]. Adjusting the schedule of waste collection to changes in

lifestyle and work/study mode during the pandemic, as well as setting priorities in the frequency of waste collection is also an important factor in effective waste processing [64]. An example in this context can be seen in the United Kingdom, where high-, medium- and low-priority waste streams are defined, with recyclable waste divided into medium- and low-priority categories, which are collected weekly or fortnightly [65]. To achieve the circular economy goals, it is also important to quickly introduce new guidelines for waste producers, including the indication of the correct way to carry out waste collection in light of the COVID-19 pandemic.

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