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Poland's Proposal for a Safe Solution of Waste Treatment during the COVID-19 Pandemic and Circular Economy Connection

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Abstract: The purpose of the study presented in this text is to show the influence of COVID-19 on waste management systems and circular economy stream, and their impact on circular economy, particularly the economic impact of the pandemic on the waste management sector, impact on circular economy objectives' implementation as well as additional challenges like the need for hygienization of waste streams during different implementation efforts, such as changes in the municipal solid waste market and different waste processes of their disposal. Additionally, some methods—such as thermal treatment—which seemed to be not fully aligned with the circular economy approach have advantages not taken into account before. Incineration of higher volume of waste affects the waste structure and will change some of the circular economy objectives. The analysis was carried out on the example of the Polish market.

Keywords: circular economy; COVID-19; SARS-CoV-2; waste management; combustible waste; incineration plant; secondary waste; RDF; heavy metals; SWOT

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1. Introduction

It is estimated that since the 20th century, society has been leading a consumerist lifestyle [1]. Despite many legal changes, the promotion of the transition from a linear to a circular economy, as well as greater public awareness, that huge amounts of raw materials are still used and more waste is generated [2].

Until 2019, with the outbreak of the COVID-19 pandemic caused by SARS-CoV-2 virus, Poland had gradually increased the amount of selectively collected waste [3]. This is the basis for increasing the share of recycling and the waste stream returned to loop [3,4]. Unfortunately, coronavirus can disrupt this upward trend [4]. Current EU targets for recycling are: 55% by 2025, 60% by 2030 and 65% by 2035 [5]. Poland has a problem in fulfilling all obligations in this area. The COVID-19 pandemic will make the situation even more difficult. Figure 1 shows municipal solid waste in Poland in 2013–2018. There is a growing recycling tendency, but it is hard to fulfill the targets:

- Minimum 50% recycling by 2020 [4].
- Maximum 30% thermal treatment by 2020 [4].
- Maximum 10% disposal by 2030 [4].

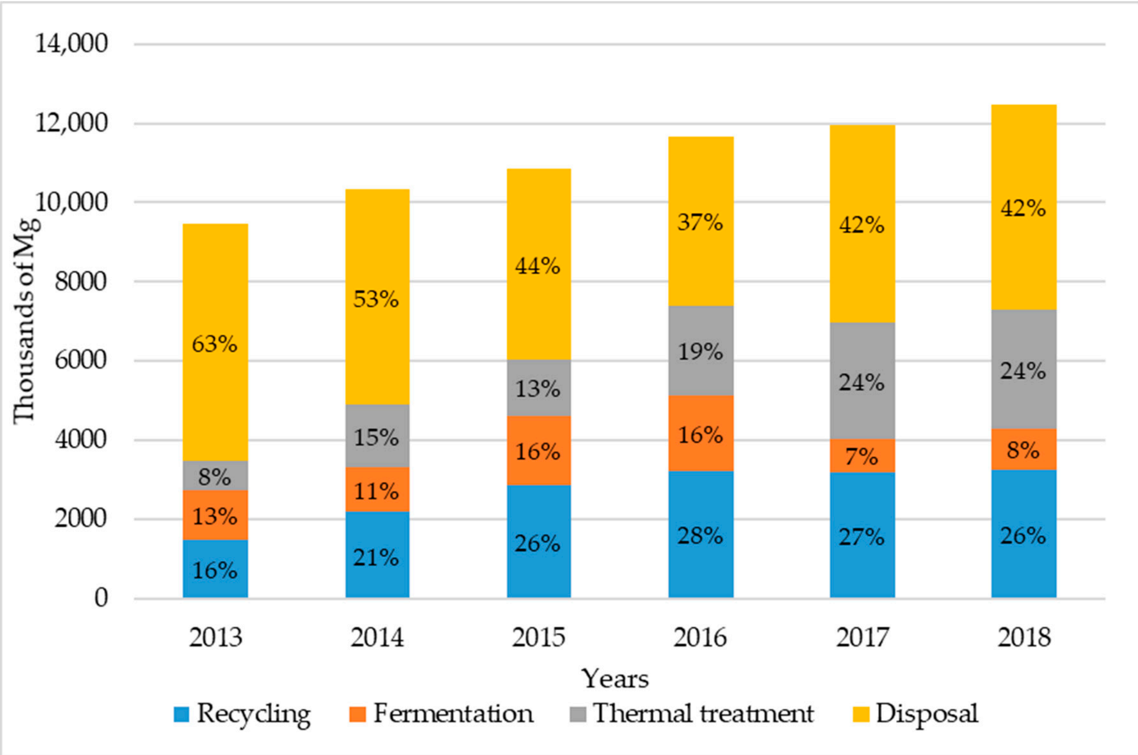


Figure 1. Municipal solid waste management in Poland in 2013–2018 [4].

SARS-CoV-2 coronavirus is a new type of virus and belongs to the beta-coronavirus group. It is very similar to SARS-CoV. The coronavirus is spherical in shape with a diameter of about 130 nm. Due to its small size, it can remain airborne for a long time and can easily pass through many protective materials [6]. Coronavirus is a pathogen different from other viruses, bacteria, and pathogenic microorganisms known to the waste management industry on a daily basis. Figure 2 shows the persistence of coronavirus on the surface of different wastes [7].

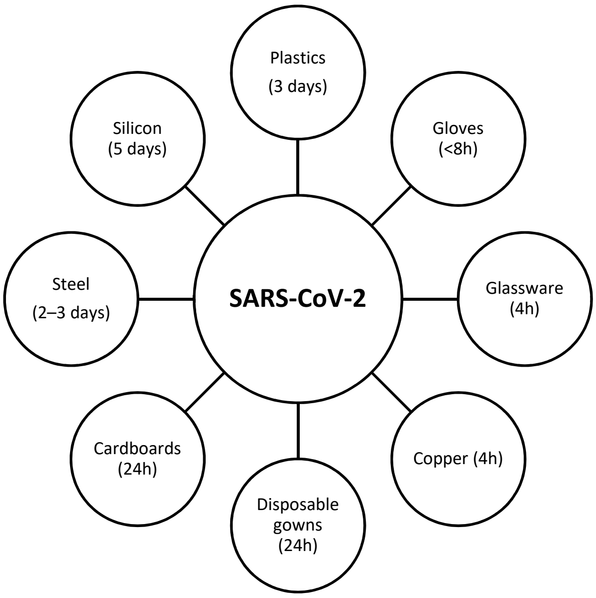


Figure 2. Persistence of SARS-CoV-2 coronavirus on different wastes [7].

Coronavirus persistence reaches the lowest level on glassware, copper (4 h) [7] and gloves (<8 h) [7], while it is the highest on silicon (5 days) [7], plastics (3 days) [7] and steel (2–3 days) [7]. Persistence of SARS-CoV-2 on cardboards and disposal gowns is approximately 24 h [7].

Agencies and countries have introduced many suggestions and guidelines on how to minimize the risk of coronavirus in waste management:

- WHO (World Health Organization): gave message that all physical workers must be equipped with proper personal protective equipment (PPE), e.g., facemasks, medical gloves, aprons, and disposable protecting cloths. The World Health Organization estimates that currently around 89 million face masks and 76 million gloves are used worldwide.
- US EPA (The United States Environmental Protection Agency): introduced guidelines for recycling and sustainable management of food wastes during the COVID-19 outbreak.
- U.S. OSHA (United States Occupational Safety and Health Administration): defined the safety guidelines, e.g., strict engineering and administrative controls, safe work practices, and proper PPE.
- SWANA (Solid Waste Association of North America): reminded that solid waste collection, processing, and disposal are a crucial public service.
- EC (European Commission): published the guidelines to include preventing or reducing distortions in waste management services.
- China: "The Ministry of Ecology and Environment of the People's Republic of China issued "COVID-19 Infected Pneumonia Medical Waste Emergency Disposal Management and Technical Guide. The infectious medical wastes generated during the COVID-19 pandemic should be strictly packaged according to the standards for special packaging bags, containers, and warning signs for medical wastes. Medical waste disposal units, e.g., hazardous waste incineration plants, domestic waste incineration plants, industrial furnaces, and other emergency disposal methods shall give priority to the collection and disposal of infectious medical waste. The standard for pollution control on medical waste treatment and disposal" (GB39707-2020) will be implemented [8,9]".

2. Quantitative and Qualitative Change in the Waste Stream during the SARS-CoV-2 Pandemic

Waste management is particularly sensitive to the impact of potential epidemics. Its stagnation may consequently lead to further sanitary and epidemiological threats. The SARS-CoV-2 pandemic disrupted the established cooperative relationships within it [10,11]. During the SARS-CoV-2 pandemic, there was a quantitative and qualitative change in the waste stream. The volume of industrial waste decreased by 50%. The reason for this was plant downtimes as well as difficulties and irregularities in raw material supply [3,12].

The municipal waste stream has changed significantly in quality because:

- The stream of municipal waste from non-residential properties has decreased. The amount of waste collected from residential properties has increased. Sending office workers to home offices was the reason. This created logistical problems for waste collection. The collection system and the waste collection schedule in the cities and neighboring towns had to be redefined;
- The amount of spoiled food has increased, especially with short expiry dates due to the outbreak of panic about the risk of food shortages in shops. Waste treatment facilities have received a different waste stream with high humidity and a bad smell;
- The stream of packaging waste has increased due to online shopping (paper, cardboard, plastic);
- The number of disposable items has increased (protective masks, rubber and foil gloves, plastic bags and disposables);
- Due to the lower volume of industrial waste and the higher amount of municipal waste, the calorific value of waste available on the market has decreased, which

indirectly translates into the production of fuels from waste. In contrast, the amount of waste with high moisture content has increased [3,13].

3. Waste Management vs. the SARS-CoV-2 Pandemic

The waste hierarchy is based on waste minimization, preparation for re-use, recycling, recovery and disposal [8–10]. Disposal is not part of a circular economy and recovery should be the final stage of waste treatment [11–14]. The SARS-CoV-2 pandemic has disrupted existing waste management due to prioritizing the protection of public health and the health of waste management workers. Disruption of waste collection from urban areas could cause other epidemiological risks [15].

3.1. Minimalization

In 2019, 114.1 million tons of industrial waste and 12.8 million tons of municipal waste were collected in Poland. This means that the collected volume of industrial waste was almost 9 times higher than the amount of municipal waste. During the SARS-CoV-2 pandemic, there was a significant reduction in industrial waste generation. This had a positive impact on waste minimization, even with the increase in municipal waste [3].

3.2. Preparing for Re-Use and Recycling

Waste generated by COVID-19 sufferers and those in quarantine is classified as municipal waste. This waste should be prepared before it is disposed of (e.g., wait 72 h from closing to handing over the bag, spray the bag with a virucidal disinfectant, do not compact the waste, do not fill the bag completely, etc.).

Personal protective equipment (PPE) items such as gloves or masks used by healthy persons should be placed in the mixed waste container.

According to the Act of 31 March 2020, on amending the Act on special solutions related to preventing, counteracting and combating COVID-19, and other infectious diseases and crisis situations caused by them, as well as some other acts, the Authority may change or exclude the requirements for selective collection of municipal waste specified in the regulations on maintaining cleanliness and order in communes and in the regulations issued on the basis of Act 4a (1) of the Act of 13 September 1996 on maintaining cleanliness and order in communes (*Journal of Laws* of 2019, item 2010 and 2020, and of 2020, item 150 and 284). The Authority may also order the storage or thermal processing of municipal waste without (any or specified) pre-treatment processes [16].

The new Act allows for more liberal handling of waste. The options presented in the Act are often cheaper and easier methods of managing waste. Unfortunately, this may result in a reduction of waste sent for recycling, which does not fit into the circular economy.

Recycling can be dangerous for waste management workers during a pandemic. Recycling often starts at the mechanical–biological waste treatment stage, where manual sorting takes place. Workers' protective clothing is not designed to prevent SARS-CoV-2 infection. Some cities, e.g., in the USA, have stopped recycling for fear of workers' health, and Italy has completely banned sorting waste for infected residents. Although waste collection continued, it was not always selective [13].

Falling oil prices also had a negative impact on recycling. Significant price differences between the recycled product and the raw material product exacerbated the reduction in its demand [4].

One of the waste treatment methods is anaerobic digestion. Fermentation is distinguished: psychrophilic, mesophilic, thermophilic. Psychrophilic fermentation takes place below 25 °C and lasts 70–80 days. Mesophilic fermentation takes place at 30–40 °C and lasts about 30 days. Thermophilic fermentation takes place at temperatures above 40 °C and lasts 15–20 days. The SARS-CoV-2 virus dies at temperatures above 65 °C, therefore, it will not die due to the temperature in the process of anaerobic digestion. Its viability is 9 days, therefore, it will not survive any kind of fermentation as the shortest is about 15 days. Automated anaerobic digestion will be a good option for biodegradable waste [6,9–11].

3.3. Recovery

The thermal treatment of waste is the safest method of disposal, especially during a pandemic. The high temperatures used during incineration in, e.g., incineration plants and cement kilns favor the inactivation of bacteria, viruses and other pathogens. In addition, these plants are used in highly automated processes. In the case of incineration plants, waste from the city is transported by a garbage truck to the plant site, where it is directly dumped into a bunker without human intervention. A gripper transfers the waste into the incineration chamber, where the temperature is over 850 °C. For cement plants, the process temperature can reach up to 2000 °C. Incineration is carried out mainly in final facilities where, in addition to the recovery of heat and electricity from the waste, combustion by-products such as slag, fly ash and bottom dust are generated. In order to ensure that the secondary waste after the incineration process is not harmful for the environment, it is necessary to develop the technology for its utilization, e.g., in the construction industry. If all the secondary waste generated by an incineration plant is used, the process will become part of a circular economy [17–19].

In Poland, there is still a lack of adequate capacity for intermediate and, above all, final facilities. SARS-CoV-2 pandemic delays new investments and modernization of existing plants [20].

Thermal treatment in times of a pandemic is the best solution, but due to the lack of technology for managing all secondary waste, it does not fit into the circular economy as a whole [21,22].

3.4. Disposal

Landfilling is not part of the circular economy. However, apart from recovery, it is the safest method for waste disposal during a pandemic. Landfilling does not require significant human involvement, which means that there is little chance of contamination with the virus. In Poland, during the SARS-CoV-2 pandemic, there are plans to abandon the possibility of storing combustible waste in landfill sites, which encourages the use of this process as an option for waste management. The landfill process is the cheapest waste disposal option, making many entities keen to benefit from the lifting of the ban on landfilling waste above 6 MJ/kg. Lifting the ban should only encourage temporary storage to inactivate the virus. However, the reality may be different and the waste will never be recycled or recovered [23,24].

3.5. Informal Sector

In Poland, up to 3 million tons of waste may be off the register and there is currently insufficient capacity at final facilities for 1.9 million tons of combustible waste [25,26].

The gray market in the waste industry is projected to increase due to the outbreak of the SARS-CoV-2 pandemic because of the delay in the development of Waste Database (BDO in Polish) and the reduction in ongoing audits of companies. The delay of Waste Database (BDO in Polish) allows illegal trade of documents proving recycling and recovery. This results in uncontrolled waste treatment, which often involves illegal dumping, burial, discharge into rivers, and waste incineration. Inspections by legitimate institutions are less frequent, causing illegal practices to grow. The uncontrolled stream of waste, found in the informal sector, is extremely dangerous for the environment and often for people, making it completely incompatible with a circular economy [25,26].

3.6. Impact of SARS-CoV-2 on the Circular Economy

Thermal treatment is the safest option of waste management during a pandemic [12]. There is one problem—the more waste is incinerated, the more secondary waste is created [4]. Europe generated approximately 29.4 million mg of secondary waste in 2017 from 492 million mg of municipal solid waste and 0.24 million mg only in Poland. If the secondary wastes were managed, the circuit would be closed (Figure 3) [27]. Figure 3 shows an ideal circular economy [28].

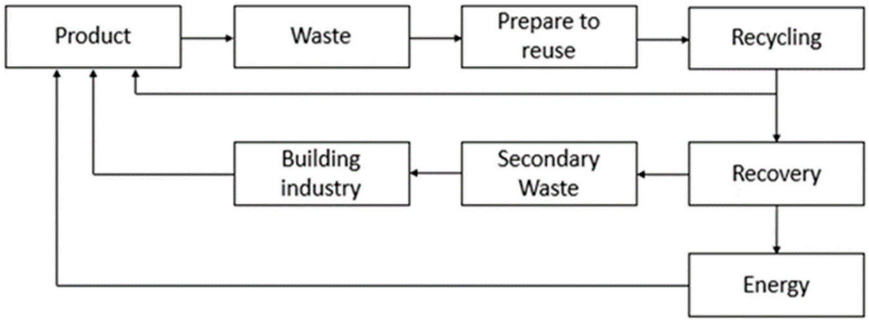


Figure 3. Ideal circular economy.

The ideal solution is to manage secondary waste with a high content of heavy metals, sulfur and chlorine [2].

4. Changes in Waste Management Caused by Minimizing the Risk of SARS-CoV-2 Virus Infection

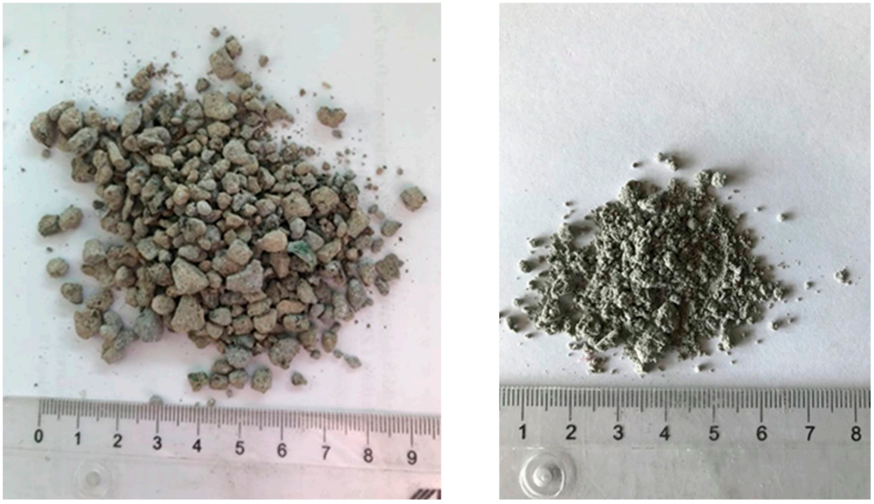
There are many ways to reduce the potential for SARS-CoV-2 virus infection in the waste management system. Unfortunately, the system has not been perfect so far, and the pandemic has revealed many gaps. Responding quickly and making changes is not easy, but is possible. Preventive measures can include:

- Switching the office staff system to remote working;
- Changing the operational staff to a 7 h mode and using the eighth hour for disinfecting vehicles or process equipment. The teams will not be in contact with each other, which will prevent mass contamination and shutdown of the entire plant;
- The use of a separate container for waste for infected or quarantined people. This will enable separation of the waste, after which the entire container will be sent for thermal treatment. This will minimize the risk of contamination for those working in the waste separation process or transferring the waste to other processes (e.g., forming fuel from waste) [29,30];
- Temporary storage (5–9 days) of municipal waste in landfills. However, this is impossible due to the regulation stipulating the maximum calorific value of waste (6 MJ/kg) allowed for entering the landfill. There is a need to change the regulation about calorific value and, after all, the Ministry of Environment temporarily should suspend the ban on storing the combustible fraction [24];
- The use of disinfection with nanosilver (about 12–15 EUR/5l g) or titanium oxide ions (15–40 EUR/100 g). However, this is an expensive solution that could increase the waste collection prices [31];
- The use of UV lamps. It is not a completely safe solution, but it is relatively cheap [4,32];
- Development of Public Private Partnership. The public sector is the owner of the waste and has a lot of information, e.g., about people in quarantine. The private sector has knowledge and experience in waste management. Cooperation between public and private sectors contributes to better and more efficient operation and waste management [4];
- Abolition of certain regulations and restrictions to develop, upgrade and expand waste treatment infrastructure [4,32].

Safety rules and protection against infection of employees in the waste management industry is particularly important because of the plant downtimes or the lack of personnel to collect municipal waste from cities may result in another epidemiological threat, e.g., uncontrolled reproduction of pests and rodents such as rats or pigeons [29,33].

5. Secondary Waste Management as the Last Element of a Circular Economy

Two main secondary waste types are generated during incineration of municipal solid waste: hazardous fly ash and non-hazardous slag. The fly ash in Waste Catalogue is classified under the code 19 01 07* (* means that this is hazardous waste.)—solid waste from gas treatment and slag is under the code 19 01 12—slags and bottom ash [30] (different than hazardous) [34,35]. The fly ash is light gray and it has a very fine fraction (specific surface area 745 m^2/kg). It is very hygroscopic and dusty with an acrid smell. The slag is gray with visible glass particles. The slag is similar to aggregate, while the fly ash is similar to cement. Figure 4 shows slag (Figure 4a) and fly ash (Figure 4b).



(**a**) (**b**)

Figure 4. Municipal solid waste incineration plant secondary waste: (**a**) Slag after valorization; (**b**) Fly ash.

The basic technical properties of secondary waste under test are presented in Table 1. The moisture content in the secondary waste was specified in accordance with the PN-EN ISO 18134-3:2015-11 Standard [36], while the bulk density was carried out in accordance with the PN-EN 1097-3:2000 Standard [27].

Table 1. Basic technical properties of fly ash and slag.

Properties	Symbol	Unit	Fly Ash	Slag
Moisture	M	%	1.45	8.65
Bulk density	ϱ	kg/m^3	469.03	1077.33

The total moisture in fly ash is 1.45% and 8.65% in slag. Slag prior to use in concrete should be dried to reach the moisture level below the minimum of 3% because of pozzolanic activity [27]. The bulk density for fly ash is 469.03%, while for slag is 1077.33%. This is an important parameter for carrying secondary waste, especially for fly ash requiring a special vehicle.

The use of secondary waste in the building industry is not easy and obvious, although slag belongs to non-hazardous waste but fly ash (or APCr—Air Pollution Control residues) and bottom ash are hazardous wastes. Until now, this hazardous waste has been stored underground but there are a lot of research projects underway on how to manage it. One must be aware of the heterogeneous composition of the municipal waste and, consequently, the variable composition of the secondary waste. The tables below show the content of components in fly ash, determined in October. Table 2 presents the results of heavy metal concentration tests for fly ash and slag.

Table 2. Content of heavy metals in fly ash.

Heavy Metal	Symbol	Unit	Fly Ash	Slag
Manganese	Mn	ppm	787.1	403.04
Cadmium	Cd	ppm	98.811	blq.
Nickel	Ni	ppm	46.472	10.41
Lead	Pb	ppm	907.83	176.47
Cobalt	Co	ppm	10.036	6.18
Chrome	Cr	ppm	80.13	49.32
Copper	Cu	ppm	404.82	2484.1

blq: Values below the limit of quantification.

The determination of heavy metal content in secondary waste is carried out in two stages. First, the waste is mineralized according to the PN-EN 13657:2006 Standard, and then, heavy metals in the mineralized matter are determined using the method of atomic emission spectrometry with excitation in inductively coupled plasma (ICP-OES) according to the PN-EN ISO 11885:2009 Standard [37].

Managing fly ash is more complicated than managing slag. Table 1 shows that the concentration of heavy metals in fly ash is much higher than in slag. The exception is copper because it is a non-magnetic heavy metal and it cannot be removed in magnetic separators during slag cleaning. The level of manganese, cobalt, and chrome is about 2 times higher, and 4 times higher for nickel and lead. The test results shown may significantly differ depending on the waste to be incinerated or the season.

6. Results

6.1. Circular Economy vs. COVID-19

The quoted facts show that there is a big challenge for the circular economy during the COVID-19 pandemic due to, for example, increase of single-use plastics and products including fabric masks or full face masks. The need of protection against infection has multiplied the use of packaging. In fact, plant downtimes reduce the amount of generated waste, especially in the automotive or mining industry, however, the poor situation on the market affects the waste management.

The safest waste treatment is thermal treatment—high temperature and almost fully automated cycle minimizes the risk to employees. Storage is a safe process, too. Unfortunately, recovery or disposal are in the last places on the pyramid hierarchy.

It is possible to use recycled glass infinitely, recycled plastics a dozen times, and recycled paper a few times. This is the aim of the circular economy—use as long as possible. Recovery should be at the end of the process when the life cycle of product or material will come to an end, so when materials lose their properties including viscosity and color, their contamination increases, etc. Immediate incineration of waste does not use its full potential, and it squanders material (e.g., glass can never be recovered because it is incombustible). Despite the many negative features of incineration, it should be remembered that this process allows for energy recovery and some other materials (Table 3).

Until the pandemic ends, after all, it is safe to choose thermal treatment, however, it is just only one option to close the loop—to manage and use the secondary waste from an incineration plant. New problems require new solutions. This is a chance to develop secondary waste management and to make the incineration process more effective [38].

Table 3. Summary of the most important data from Poland incineration plants (year: 2018; processing capacity per year: 220,000 mg) [38].

Parameter		Unit	Value
Amount of waste		Mg	209,973
Average calorific value of waste		GJ/mg	7.8
Heat energy produced		GJ	300,370
Electricity generated		MWh	112,546
Amount of solid waste generated and managed from waste gas treatment		Mg	7784
The amount of crude slag formed and processed		Mg	55,909
Including:	Amount produced and managed furnace slag	Mg	51,937
	Amount produced and managed ferrous metals	Mg	3284
	Amount produced and processed non-ferrous metals	Mg	511

6.2. SWOT—Influence of COVID-19 on Waste Management and Circular Economy

COVID-19 has been having an incredibly detrimental influence on the whole financial market but in some cases, it has a positive impact on the environment and technology. The number of flights and the level of exhaust emissions have been reduced, industry downtimes result in lower waste amounts, water in some parts of the world has become cleaner, etc., and hence, there are some positive sides to the bad situation. The SWOT (Strengths, Weaknesses, Opportunities, and Threats) table (Table 4) shows the impact of COVID-19 on circular economy and waste management market [39].

Table 4. SWOT—(Strengths, Weaknesses, Opportunities, and Threats in the circular economy and waste management due to COVID-19.

Strengths	Weaknesses
less amount of waste because of lockdown of installations	threat to employees unstable economy unsuitable processes (e.g., interim storage) highlight the weaknesses of waste management increase of single-use products (masks, gloves, bags, etc.)
Opportunities	**Threats**
development of digitalization development of new technologies development of process automation new investments	waste management installation downtime failure to reach recycling targets disorder of circular economy contamination of raw materials (because of temporary storage) development of thermal treatment instead of recycling the growth of the informal sector

Opportunities include development of digitalization and automatization. Process automation avoids human contact with waste. It is a good solution in a pandemic. Virtually every branch of waste management can be automated. From collection and transport to processing. There are intelligent litter bins that automatically separate waste. Waste collection can also be fully automated, by retractable underground bins or a solution by underground waste transport, thanks to underground corridors. This modern solution involves the use of negative pressure.

Waste sorting can also be automated by grinding, sieving, gravity separation using liquid or air, magnetic separation and highly-advanced spectrophotometric sorting technologies using ultraviolet electromagnetic radiation, visible light, near infrared and laser.

The use of automation will not only allow for contactless waste management, but also improve the efficiency of recycling. Automation and digitization, however, require financial outlays and qualified staff. Currently, there are many highly automated installations, but they are found in more developed countries [39,40].

7. Conclusions

The SARS-CoV-2 pandemic is slowing down new investments and modernizations of existing waste treatment facilities. In addition, fewer facility inspections are increasing the amount of inadequately managed waste, revealing gaps in the system.

The biggest changes have been noticed in the waste collection system due to switching to remote working and plant shutdowns. The waste stream, primarily the municipal waste, has also changed because of the restrictions imposed. The level of Internet sales has increased, thus increasing the amount of packaging waste. Public panic has led to increase the volume of waste coming from the food industry. Due to the risk of virus transmission, waste should be temporarily stored or directly subjected to the process of incineration, which increases the possibility of its withdrawal from circulation and the eventual change of its physicochemical properties.

The SARS-CoV-2 virus pandemic has changed the waste management industry, but by revealing its imperfections, it has shown certain appropriate directions for development. Digitization and automation of processes will increase the share of recycling and reduce the risk of diseases for people dealing directly with waste. The pandemic has certainly temporarily threatened the development of the circular economy. However, once it is over, the development of new technologies may accelerate, becoming more intense. COVID-19 has demonstrated the possibility of remote working and supervising many operations remotely, which will change the face of the current economy.

Summing up, the duration of the pandemic has a negative impact on the development and implementation of the circular economy, but some studies indicate that things may improve rapidly after the pandemic is over due to induced behaviors [41]. In times of crisis and panic caused by a pandemic, entities consider various modern solutions, which stimulate the development of waste management. The result of preventive actions may be the automation of the process and digitization of the industry.

8. Discussion

The SARS-CoV-2 pandemic has revealed many failures in the waste management system. The lack of an established and functioning Waste Database may contribute to the development of an informal sector in Poland. Lack of sufficient processing capacity for final facilities makes it impossible to manage contaminated waste. The incineration process does not fully fit into the idea of a circular economy due to the lack of appropriate technology for managing secondary waste. Insufficient automation of recycling processes and availability of appropriate personal protective equipment (PPE) as well as disinfection of rooms cause the risk of SARS-CoV-2 infection for operational employees in the waste management industry. These system gaps demonstrate the number of technological challenges and growth opportunities in the waste management market. The pandemic has slowed down the development of the industry and increased non-systemic risks, which directly threatens the effective implementation of the circular economy.

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